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Durability and Efficacy of Tricuspid Valve Repair in Patients Undergoing Left Ventricular Assist Device Implantation

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ABSTRACT

OBJECTIVES This study sought to determine the durability of tricuspid valve repair (TVr) performed concurrently with left ventricular assist device (LVAD) implantation and its association with the development of late right heart failure (RHF).

BACKGROUND Surgical management of tricuspid regurgitation (TR) at the time of LVAD implantation is performed in an attempt to reduce the occurrence of postoperative RHF. Limited data exist regarding the durability of TVr in patients with LVAD as well as its impact on development of late RHF.

METHODS A retrospective review was conducted of consecutive adult patients who underwent durable LVAD implantation and concurrent TVr at the authors' institution between 2009 and 2017. Late RHF was defined as readmission for HF requiring inotropic or diuretic therapy. TVr failure was defined as moderate or severe TR at any follow-up echocardiographic examination after LVAD implantation.

RESULTS A total of 156 patients underwent LVAD and concurrent TVr during the study. Of the total, 59 patients (37.8%) had a failed TVr. The mean duration of echocardiographic follow-up was 23 ± 22 months. Of the 146 patients who were discharged after the index hospitalization, 53 patients (36.3%) developed late RHF. Multivariate Cox proportional hazard analysis demonstrated that TVr failure was an independent predictor of late RHF development (hazard ratio: 2.62; 95% confidence interval: 1.38 to 4.96; p = 0.003).

CONCLUSION Failure of TVr in this cohort occurred at a significant rate. Failure of TVr is an independent risk factor for development of late RHF. Future studies should investigate strategies to reduce recurrence of significant TR.
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Advances in the technology of rotary flow ventricular assist devices (VAD) have led to improvement in their efficacy, implantability, duration of support, and patient outcomes (1-3). Despite incremental improvement in overall survival, right heart failure (RHF) following durable left VAD (LVAD) implantation remains an important, unresolved issue. This has been recently highlighted in the MOMENTUM 3 (Multicenter Study of magnetically levitated Technology in Patients Undergoing

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ABBREVIATIONS AND ACRONYMS

LVAD = left ventricular assist device

RHF = right heart failure

RV = right ventricle

RVAD = right ventricular assist device

TAPSE = tricuspid annulus plane systolic excursion

TR = tricuspid regurgitation

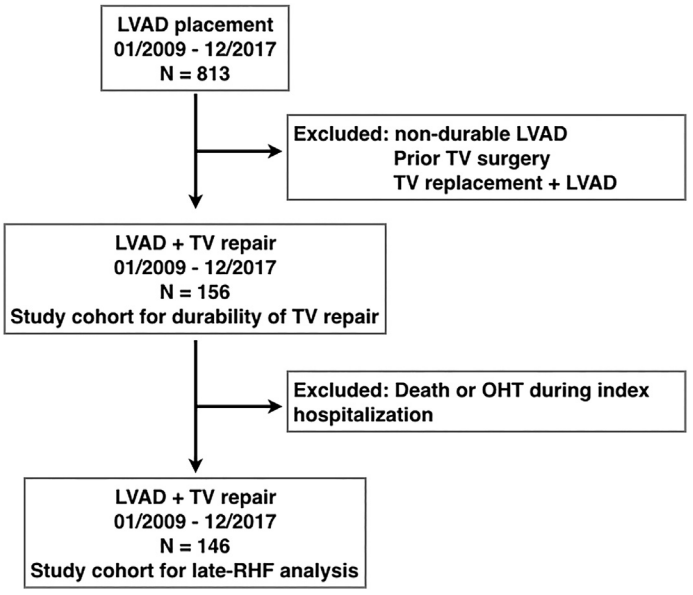
TV = tricuspid valve

TVr = tricuspid valve repair

Mechanical Circulatory Support Therapy with HeartMate3) trial, in which heart failure remained an important common cause of death following LVAD implantation (2,4). Furthermore, new devices do not appear to be effective in reducing the rate of RHF in these patients. Although early RHF is well documented (5,6), there is increased recognition of late RHF. Late RHF has been reported to occur at rates of 11% to 16% and are associated with worse patient outcomes (7–9).

Functional tricuspid regurgitation (TR) frequently accompanies right ventricular (RV) dysfunction following LVAD implantation, likely as a result of structural changes in the RV. Pre-LVAD implantation severity of TR has emerged as 1 of the independent predictors of post-LVAD implantation, early RHF (10). Concurrent tricuspid valve (TV) surgical interventions have been advocated in order to reduce the risk of RHF following LVAD implantation and in order to improve related clinical outcomes. However, consensus and high quality data for the benefits of this strategy do not exist. Some studies have suggested that concurrent tricuspid procedures reduce hospitalization and the incidence of RHF and postoperative renal dysfunction (11,12).

FIGURE 1 Diagram of the Study Population



Study population, inclusion, and exclusions criteria are shown. LVAD = left ventricular assist device; OHT = orthotopic heart transplantation; RHF = right heart failure; TV = tricuspid valve.

However, a more recent analysis by the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) showed that concurrent TV surgery in patients with moderate and severe TR did not confer any survival benefit compared to that in patients who underwent LVAD implantation alone (13). Similarly, a different report from the Society of Thoracic Surgeons concluded that concomitant TV surgery in LVAD patients with moderate to severe TR did not reduce early death or right VAD (RVAD) requirement and was associated with more postoperative morbidity (14). Whether these negative conclusions are related to the durability of the procedure and TR recurrence is unclear, as the durability of the repair by annuloplasty has not been studied in this unique population.

Therefore, the present authors conducted a single-center retrospective review to evaluate the durability of concurrent TV repair (TVr) in patients undergoing durable LVAD implantation and to examine the incidence and association of TVr failure with the development of late RHF.

METHODS

PATIENT POPULATION. Following Duke University Institutional Review Board approval, medical records from consecutive adult patients who underwent durable LVAD implantation from January 1, 2009, to December 31, 2017, were examined. Detailed demographic, clinical, and echocardiographic data were collected from quality controlled, prospectively entered databases, as well as from hospital medical records. All adult patients (older than 18 years) who underwent LVAD implantation and concurrent TVr were included in the study. Exclusion criteria included nondurable LVAD implantation, TV replacement at the time of LVAD implantation (5 patients), and prior TV surgery. Patients who died or who underwent orthotopic heart transplantation during the index hospitalization for LVAD implantation were excluded from the analysis of late RHF (Figure 1).

Demographic and clinical data were extracted from a prospective, institutional LVAD database as well as from individual chart reviews. Pre-LVAD implantation hemodynamics were determined on the basis of the most recent right heart catheterization prior to the index surgery.

Pre-Implantation echocardiographic data regarding RV function, TV annulus diameter, tenting height and tenting area of leaflets, and TR severity were obtained, either from preoperative transthoracic echocardiographic (TTE) studies or from intraoperative

TABLE 1 Preoperative and Procedural Characteristics in Patients Undergoing Durable LVAD Implantation and Concurrent TVr

Baseline characteristics	
Number of patients	156
Males	115 ± 73.7
Age, yrs	58.21 ± 12.55
Body mass index, kg/m^2	30.17 ± 7.55
Body surface area, m^2	2.14 ± 0.35
Creatinine, mg/dl	1.69 ± 0.72
Hemoglobin, g/dl	10.96 ± 1.86
AST, U/l	82.54 ± 349.06
ALT, U/l	63.77 ± 152.88
Total bilirubin, mg/dl	1.94 ± 1.81
INR	1.41 ± 0.5
Diabetes	41 (26.2)
COPD	25 (16)
ICD	125 (80.1)
Previous sternotomy	50 (32)
Right heart catheterization	
CVP, mm Hg	16.4 ± 6.53
PCWP, mm Hg	25.52 ± 7.61
CVP/PCWP, mm Hg	0.64 ± 0.22
Mean PAP, mm Hg	39.46 ± 9.08
PVR	3.94 ± 2.67
Treatment intent	
BT	28 (18)
DT	126 (80.8)
DT to BTT	2 (1.2)
Heart failure cause	
Congenital	1 (0.6)
Dilated myopathy (viral)	2 (1.2)
ICM	62 (40)
ICM/NICM	2 (1.2)
NICM	89 (57)
Echocardiographic parameters preoperative	
RV dysfunction	
Missing	1 (0.6)
Normal	2 (1.2)
Mild	29 (18.5)
Moderate	86 (55.3)
Severe	38 (24.4)
TAPSE, cm	1.3 ± 0.49
TV diameter, cm	4.51 ± 0.66
TV tenting height, mm	8.58 ± 3.23
TV tenting area, cm^2	2.17 ± 2.37
TV regurgitation	
Missing	1 (0.6)
Mild	11 (7)
Moderate	91 (58.4)
Severe	53 (34)
Procedural characteristics	
LVAD type	
Heartmate II (Abbott)	101 (64.7)
Heartmate III (Abbott)	16 (10.3)
Heartware HVAD (Medtronic)	39 (25)
RVAD at implantation	
Planned RVAD	4 (2.5)
Unplanned RVAD	3 (2)
Concurrent procedure (other than TVr)	41 (26.2)
TV annuloplasty ring type	
Physio-Ring (Edwards Lifesciences)	4 (2.5)
Tailor (St. Jude Medical)	24 (15.5)
Tri-Ad (Adams, Medtronic)	128 (82)
TV annuloplasty ring size	
26 mm	48 (30.7)
28 mm	66 (42.3)
TV regurgitation post-CPB	
Missing data	1 (0.6)
Trivial/none/mild	130 (83.7)
Moderate	17 (10.8)
Severe	4 (2.4)
RVAD	4 (2.5)
Died at implantation hospitalization	8 (4.8)
Underwent transplantation at hospitalization	2 (1.2)

Values are mean ± SD or n (%).

ALT = alanine aminotransferase; AST = aspartate aminotransferase; BT = bridge to transplant; COPD = chronic obstructive pulmonary disease; CPB = cardiopulmonary bypass; CVA = cerebrovascular accident; CVP = central venous pressure; DT = destination therapy; ICD = implantable cardioverter cardioverter-defibrillator; ICM = ischemic cardiomyopathy; INR = international normalized ratio; LVAD = left ventricular assist device; NICM = non-ischemic cardiomyopathy; PAP = pulmonary artery pressure; PCWP = pulmonary capillary wedge pressure; PVR = pulmonary vascular resistance; RV = right ventricle; RVAD = right ventricular assist device; TAPSE = tricuspid annular plane systolic excursion; TV = tricuspid valve; TVr = tricuspid valve repair.

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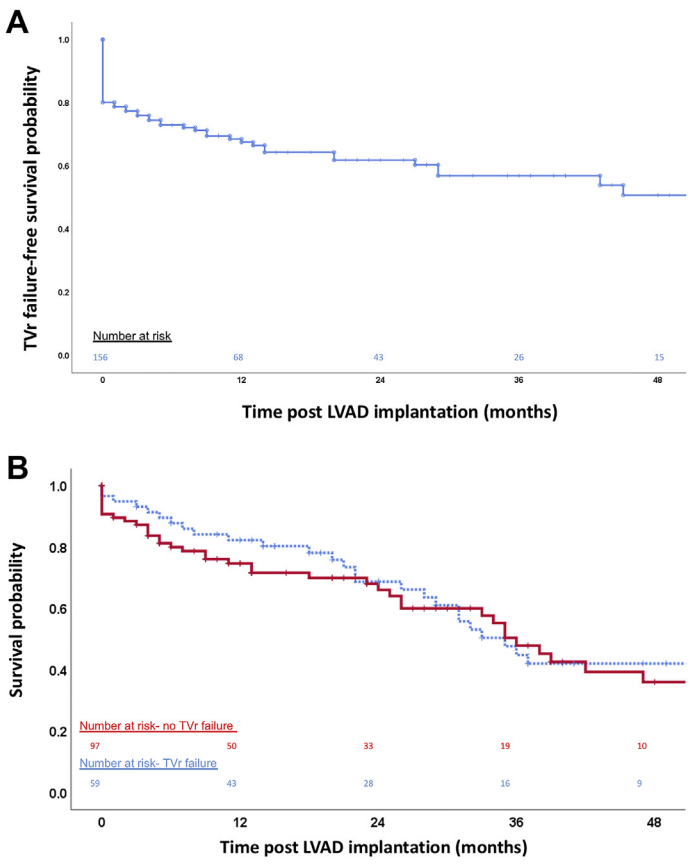
pre-cardiopulmonary bypass (CPB) transesophageal echocardiographic (TEE) studies. Grading and definitions were obtained according to published guidelines (15,16). Post-implantation echocardiographic data were obtained from intraoperative post-CPB TEE studies and from post-implantation follow-up TTE studies.

At the time of LVAD implantation, the TV was approached with the heart beating by using bicaval cannulation and a right atriotomy. Annular sutures were placed circumferentially while avoiding the annulus at the medial aspect of septal leaflet. These sutures were passed through an undersized ring and tied to secure the annuloplasty. When present, pacer or defibrillator leads were freed of adhesions to the leaflets and positioned centrally in the valve orifice.

OUTCOMES. TV repair failure was defined as moderate or severe TR on any postoperative follow-up echocardiographic study.

Late RHF was defined as any readmission for right-sided heart failure after the index hospitalization for LVAD implantation, requiring medical treatment with diuretic agents or inotropes or surgical implantation of an RVAD (17). The diagnosis of late RHF was based on clinical signs. Occurrences of late RHF were identified by a clinician blinded to the echocardiographic data by individual chart review and were based on

FIGURE 2 Tricuspid Valve Repair Failure



(A) Freedom from TVr failure over follow-up. **(B)** Survival stratified by TVr failure. LVAD = left ventricular assist device; TVr = tricuspid valve repair.

clinical findings such as worsened edema, ascites, weight gain, jugular venous distension, and fatigue. Readmissions due to device failure, pump thrombosis, inflow or outflow obstruction, gastrointestinal bleeding, drive line fracture or infection, or pulmonary disease were excluded.

STATISTICS. Data are median with 95% confidence intervals (CIs) or mean ± SD for continuous variables or as counts with percent for categorical variables. Clinical and demographic variables between the outcome groups were analyzed using Wilcoxon rank sum or *t*-tests for continuous variables and chi-square or Fisher exact tests for categorical variables as appropriate.

Characteristics were screened for association with late RHF. Variables associated at the nominal p value of ≤0.10 were significant in the univariable analysis were considered in a selection for a Cox regression model to assess the independent association and statistical significance of each variable with time to RHF admission. Variables associated with late-RHF at a p value of <0.05 level of significance were retained in the final model.

The Kaplan-Meier method was used to analyze survival and freedom from late RHF readmission associated with TVr failure. The log rank test was used to compare differences in late RHF between those with TVr failure versus those with no TVr failure during the follow-up period. Statistical analyses were performed using SPSS version 25 software (IBM Corp., Armonk, New York).

RESULTS

PATIENT CHARACTERISTICS AT THE TIME OF LVAD IMPLANTATION. A total of 813 patients underwent durable LVAD implantation during the study. Of these, 156 patients (19.1%) underwent concurrent TVr and constituted the study cohort. Patient characteristics are presented in Table 1. Five patients underwent TV replacement and were excluded because the low number of subjects would not allow performing a group comparison.

The mean age of the subjects was 58 years old. The cohort included 115 men (73.7%) and 89 patients (57%) who had a nonischemic cause. The types of LVADs implanted were Heartmate II (Abbott-Thoratec, Chicago, Illinois) in 101 patients (64.7%), HeartMate III (Abbott-Thoratec) in 16 patients (10.3%), and HeartWare (HeartWare International Inc., Framingham, Massachusetts) in 39 patients (25%). The most common device used for TVr annuloplasty was the Tri-Ad Adams ring (Medtronic Inc., Minneapolis, Minnesota) with the 26 mm and the 28 mm used in 48 patients (30.7%) and 66 patients (42.3%), respectively. Overall, the study cohort demonstrated evidence of pre-LVAD, end-organ dysfunction with elevated creatinine (1.69 ± 0.72 mg/dl) and total bilirubin (1.94 ± 1.81 mg/dl). Hemodynamic evaluation by right-heart catheterization demonstrated elevated filling pressures: central venous pressure of 16.4 ± 6.53 mm Hg, a mean pulmonary artery pressure of 39.46 ± 9.08 mm Hg, and a pulmonary capillary wedge pressure of 25.52 ± 7.61 mm Hg. Echocardiographic assessment showed that 124 patients (79.5%) had moderate or severe RV dysfunction by global visual assessment, and overall the study cohort demonstrated dilation of the TV annulus (mean diameter: 4.51 ± 0.67 cm).

DURABILITY OF TRICUSPID VALVE REPAIR. The duration of echocardiographic follow-up was 23 ± 22 months. A total of 1,113 echocardiographic studies, follow-up TTE, and intraoperative post-CPB TEE

studies were reviewed for recurrence of TR. The number of echocardiographic studies performed per patient was 7 ± 3.4. Of the 156 patients who underwent LVAD implantation and concurrent TVr, 59 patients (37.8%) experienced failure of TVr, as defined by moderate or severe TR on any of the follow-up echocardiographic studies (only 27 patients [17.3%] showed severe TR in 1 or more echocardiographic studies). A total of 71.2% of the patients had TVr failure diagnosed within the first 6 months. Twenty-one patients were found to have repair failures in the intraoperative post-CPB TEE study; 18 of them were discharged from the implantation hospitalization, but only 5 of those patients had moderate or severe TR at their last follow-up TTE. Freedom from failure of TVr over the study period is shown in Figure 2A. There were no differences between the survival of patients who developed TVr failure and survival in patients with durable TVr (Figure 2B).

LATE RIGHT HEART FAILURE. We have identified 146 patients who were discharged after the index hospitalization and constituted the study cohort for late RHF. Of those, 53 patients (36.3%) met the criteria for late RHF. Table 2 presents the univariate analysis of clinical, demographic, and echocardiographic characteristics between the patients who developed late RHF (RHF group) and the patients without late RHF (no-RHF group). Patients in the RHF group had a higher incidence of TVr failure (54.7% vs. 28%, respectively; p = 0.001), a higher central venous pressure:pulmonary capillary wedge pressure ratio (0.7 vs. 0.6, respectively; p = 0.027), a higher body mass index (31.3 vs. 29.5 kg/m^2, respectively; p = 0.045), and a higher serum creatinine level pre-implantation (1.8 mg/dl vs. 1.6 mg/dl, respectively; p = 0.021). There were no differences between the pulmonary artery pulsatility index in the RHF group and that in the no-RHF group (1.7 vs. 1.6, respectively; p = 0.451).

Of the 29 patients with TVr failure who developed late RHF, TVr failure was diagnosed in 21 patients before the first readmission for RHF, and TVr failure was diagnosed in 4 patients at the time of first readmission for RHF.

There were 5 variables from the univariate analysis that were included in a Cox regression model. The final multivariate model identified significant independent association between the development of late RHF and TVr failure. The results demonstrate that TVr failure is associated with 2.62-fold higher odds of being readmitted at least once for late RHF (p = 0.003; 95% confidence interval [CI]: 1.48 to 4.96) (Table 3). Moreover, Kaplan-Meier analysis demonstrated a significantly higher freedom from late RHF occurrence in patients with durable TVr than in those with a TVr failure over the follow-up period (Figure 3).

TABLE 2 Clinical and Procedural Characteristics Of Patients With and Without Late RHF

	No RHF (n = 93)	RHF (n = 53)	p Value
Baseline characteristics			
Male	70 (75.3)	39 (73.6)	0.486
Age, yrs	61 (57-65)	59 (56-63)	0.454
Body mass index, kg/m^2	27.3 (26.5-28.8)	31.3 (28.5-34.8)	0.045
Body surface area, m^2	2.1 (2-2.2)	2.2 (2.1-2.3)	0.126
Creatinine, mg/dl	1.5 (1.4-1.7)	1.7 (1.6-1.9)	0.021
Hemoglobin, g/dl	10.8 (10.4-11.2)	10.4 (10.3-11.3)	0.64
AST, U/L	36 (32-42)	28 (24-37)	0.05
ALT, U/L	28 (25-36)	26 (21-31)	0.106
Total bilirubin, mg/dl	1.5 (1.3-1.8)	1.4 (1.3-1.7)	0.834
INR	1.3 (1.3-1.4)	1.3 (1.3-1.4)	0.225
Diabetes mellitus	22 (23.7)	18 (34.0)	0.126
COPD	16 (17.2)	7 (13.2)	0.349
ICD	73 (78.5)	43 (81.1)	0.439
Previous sternotomy	27 (29.0)	21 (39.6)	0.13
Right heart catheterization			
CVP, mm Hg	17 (17-19)	18 (18-21)	0.264
PCWP, mm Hg	26 (24-28)	25 (23-29)	0.502
CVP/PCWP, mm Hg	0.6 (0.6-0.6)	0.7 (0.6-0.8)	0.027
Mean PAP, mm Hg	40 (39-43)	40 (38-42)	0.619
PVR	3.4 (3.2-4.1)	3.2 (2.8-4.1)	0.783
PAPI	1.7 (1.5-1.9)	1.6 (1.2-1.8)	0.451
Treatment intent			0.437
Bridge to transplant (BT)	18 (19.4)	8 (15.1)	
Destination therapy (DT)	73 (78.5)	45 (84.9)	
DT to BT	2 (2.1)	0 (0.0)	
Heart failure cause			0.446
Congenital	0 (0)	1 (1.9)	
Dilated myopathy (Viral)	1 (1)	0 (0)	
ICM	36 (38.7)	23 (43.4)	
ICM/NICM	2 (2.2)	0 (0.0)	
NICM	54 (58.1)	29 (54.7)	
ECHO parameters			
RV dysfunction			0.607
Missing	0 (0)	1 (1.9)	
Normal	1 (1)	1 (1.9)	
Mild	16 (17.2)	10 (18.9)	
Moderate	50 (53.8)	30 (56.6)	
Severe	26 (28.0)	11 (20.7)	
TAPSE, cm	1.2 (1.1-1.3)	1.3 (1.3-1.5)	0.436
TV diameter, cm	4.5 (4.4-4.7)	4.7 (4.5-5.0)	0.38
TV tenting height, mm	8 (8-10)	8 (8-10)	0.817

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DISCUSSION

Of the 156 patients who underwent durable LVAD implantation and concurrent TVr, 59 patients (37.8%) demonstrated TVr failure defined as moderate or severe TR at any follow-up echocardiographic study.

TABLE 2 Continued

	No RHF (n = 93)	RHF (n = 53)	p Value
TV tenting area, cm^2	2.1 (1.8–2.3)	1.9 (1.6–2.1)	0.579
TV regurgitation			0.138
Missing	0 (0.0)	1 (1.9)	
Mild	9 (9.7)	1 (1.9)	
Moderate	52 (55.9)	35 (66)	
Severe	32 (34.4)	16 (30.2)	
Procedural variables			
LVAD type			0.71
HeartMate II (Abbott)	63 (67.7)	34 (64.2)	
HeartMate III (Abbott)	9 (9.7)	4 (7.5)	
Heartware HVAD (Medtronic)	21 (22.6)	15 (28.3)	
RVAD at implantation			0.481
No	89 (95.6)	51 (96.2)	
Planned RVAD	2 (2.2)	2 (3.8)	
Unplanned RVAD	2 (2.2)	0 (0.0)	
Concurrent procedure (other than TVr)	31 (33.3)	7 (13.2)	0.282
TV annuloplasty ring type			0.98
Physio-Ring (Edwards Lifescience)	2 (2.2)	1 (1.9)	
Tailor (St. Jude Medical)	15 (16.1)	8 (15.1)	
Tri-Ad (Adams, Medtronic)	76 (81.7)	44 (83)	
TV annuloplasty ring size			0.304
26 mm	31 (33.3)	14 (26.4)	
28 mm	37 (39.7)	24 (45.2)	
TV regurgitation post-CPB			0.633
Missing data	1 (1)	0 (0)	
None/trivial/mild	77 (82.8)	46 (86.8)	
Moderate	12 (13.0)	3 (5.6)	
Severe	1 (1.0)	2 (3.8)	
RVAD	2 (2.2)	2 (3.8)	
Length of hospitalization	16 (15–19)	16 (15–20)	0.696
CVA	20 (21.5)	10 (18.9)	0.817
LVAD thrombosis	13 (15.1)	10 (18.9)	0.565
TVr failure by any ECHO	26 (28.0)	29 (54.7)	0.001
TVr failure by the last ECHO	8 (8.6)	23 (43.4)	0.001

Values are n (%) or median (95% confidence interval).
ECHO = echocardiogram; PAPI = pulmonary artery pulsatility index; other abbreviations as in Table 1.

A total of 53 patients (36.3%) of the 146 patients who were discharged after the index hospitalization, developed late RHF. In the final multivariate model, TVr failure was identified as an independent risk factor for the development of late RHF.

Tricuspid valve durability has been examined in patients with functional TR due to left-heart valve disease or LV dysfunction. The reported incidence of moderate or severe recurrent or persistent TR after TV surgery has varied widely in published reports from 6% to 42% depending on patient factors, surgical technique, duration of follow-up, and definition of TR recurrence (18). Because patients undergoing LVAD placement were excluded from these studies, their findings cannot be extrapolated to the LVAD population, given the unique issues regarding the TV which were encountered with LVAD support. These issues include extreme dilation of the RV and tricuspid annulus associated with long-standing heart failure, abnormal and dynamic ventricular septal position due to LV mechanical unloading; and frequently, the presence of permanent pacer/defibrillator leads crossing the valve. Akhter et al. (19) investigated the durability of concurrent suture annuloplasty for severe TR in a retrospective review of 35 patients undergoing LVAD implantation. At the time of discharge, 3 patients (8.6%) had moderate residual TR, and at 1 year follow-up, 4 (11.4%) and 2 (5.7%) patients had moderate and severe TR, respectively (19). Deo et al. (20) compared concurrent TV repair or replacement in 64 patients undergoing LVAD implantation. TR was graded using a 5-point ordinal scale as 1 = trivial, 2 = mild, 3 = moderate, 4 = moderate-severe, and 5 = severe. The grade of TR following the intervention was reduced significantly for the entire cohort from 3.6 ± 1.72 to 1.18 ± 1.18. There were no differences in the degree of TR reduction between the repair and replacement group according to an echocardiogram performed in the immediate postoperative period, and this reduction in TR was maintained throughout the follow-up period (median: 11.9 months) (20). Data for the durability of TV repair or replacement concomitant with LVAD implantation are scarce and originate mostly from small studies with variable surgical techniques and methodology of follow-up. In the present study, 37.8% of the patients following LVAD implantation and TVr experienced recurrence of significant TR during the follow-up period, defined as either moderate or severe TR at any follow-up echocardiographic studies. It is possible that the rate of failure in the present study was higher than that in previous studies as a consequence of stringent definition for TV repair failure, moderate or severe TR at any follow-up echocardiographic studies, different from using the last follow-up echocardiographic study as in some of the previous studies. Using the last echocardiographic follow-up, the rate of TVr failure in the present study was 21.7% (n = 34). It should be emphasized that 21 patients had repair failures intraoperatively post-CPB. However, only 27% of those patients were found to have TVr failures at the end of the follow-up period, attesting to the process of cardiac remodeling.

As an increasing number of patients are supported with devices for longer durations, assessment of long-term outcome in patients undergoing concurrent TV surgery at the time of LVAD implantation is paramount. The impact of concurrent TV repair or replacement in these patients, however, is a subject

of much debate. Maltais et al. (21) showed that concurrent TV procedures at the time of LVAD implantation promoted early reverse remodeling of the RV with a significant reduction in RV end-diastolic area. Data from patients receiving HeartWare (HeartWare International Inc.) devices in the ADVANCE (Evaluation of the HeartWare Left Ventricular Assist Device for the Treatment of Advanced Heart Failure) bridge to transplant trial and continued access protocol showed that patients with significant pre-implantation TR who did not undergo concurrent TV procedures experience an increased rate of late RHF than those who underwent TV procedures (0.19 vs. 0.05 events per patient-year; p = 0.024) (22). Han et al. (23) also showed that, despite worse baseline characteristics, patients who underwent concurrent TV procedures at the time of LVAD implantation had similar short-and long-term outcomes, suggesting a protective effect of the TV procedures. However, in an analysis of the Society of Thoracic Surgeons database, Robertson et al. (14) reported outcomes in 2,196 patients with moderate or severe TR who underwent continuous-flow LVAD implantation. Of those patients, 588 (27%) underwent concurrent TV procedures (annuloplasty performed in 81.1% of cases). Performing concurrent TV procedures did not result in any differences in operative mortality or subsequent RVAD insertion. On the other hand, after propensity score adjustment, concurrent TV surgery was associated with significantly greater intensive care unit stay (>72 h), hospital length of stay >3 weeks, total transfusion requirement, new renal failure, new dialysis requirement, and any reoperation (14). Similar results were reported in an analysis of the INTERMACS database. Of the 2,527 patients who underwent continuous flow LVAD implantation, 215 underwent concurrent TV repair. Compared with patients with similar risk profile who did not undergo TV surgery, TV repair did not confer survival benefit. The limited echocardiographic data offered by the INTERMACS database suggested that the rate of recurrent TR at 1 year follow-up for the patients who underwent concurrent TV repair was between 21% and 27% (13).

The present study is the first to investigate the association between durability of TVr and outcomes, specifically readmission for late RHF. An incidence of late RHF of 36.3% is reported. The reported incidence for late RHF in patients undergoing LVAD implantation using a similar definition varies in published reports from 11% to 16% (7–9). The likely explanation for the large discrepancy between the present results and the existing data is that the present study is the first to report the incidence of late-RHF in a selected population of patients undergoing LVAD implantation and TV repair, whereas other studies have either included patients who underwent only LVAD implantation (7,8) or have included patients who underwent LVAD implantation with only a fraction of patients undergoing other concurrent valve procedures (aortic, mitral, and tricuspid) (9). The risk factors associated with early RHF are very well described in published reports; however, there is little information regarding risk factors associated with late RHF. Some of the risk factors identified so far are tricuspid annulus diameter (7), body mass index, and blood urea nitrogen level (9). Although the present study included the variables mentioned above together with several other pre-implantation and procedural variables, the only risk factor identified in the multiple variable analysis was TV repair failure.

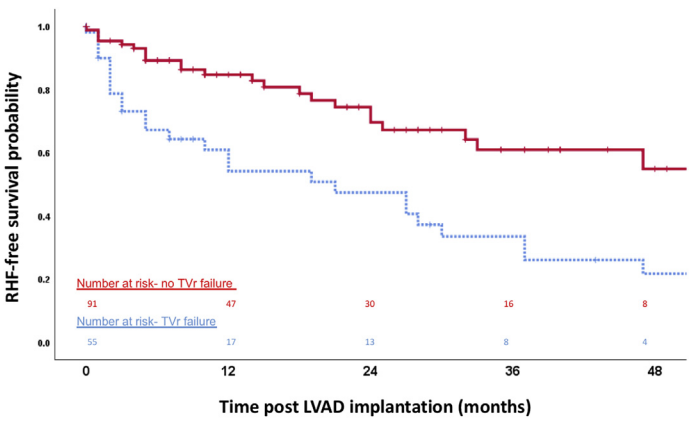
The results of this report suggest that a significant fraction of patients have recurrence or persistence of either moderate or severe TR and that TV repair failure is independently associated with late-RHF, which may provide some explanation for why clinical benefit has been difficult to show.

TABLE 3 Multivariate Cox Regression Model for the Association With Development of Late Right Heart Failure

		95% CI		
	HR	Lower	Upper	p Value
BMI, kg/m^2	0.988	0.947	1.031	0.578
Baseline creatinine, mg/dl	1.033	0.567	1.882	0.916
AST, U/L	0.99	0.98	1.000	0.054
CVP/PCWP	3.42	0.720	16.236	0.122
TVr failure	2.621	1.384	4.963	0.003

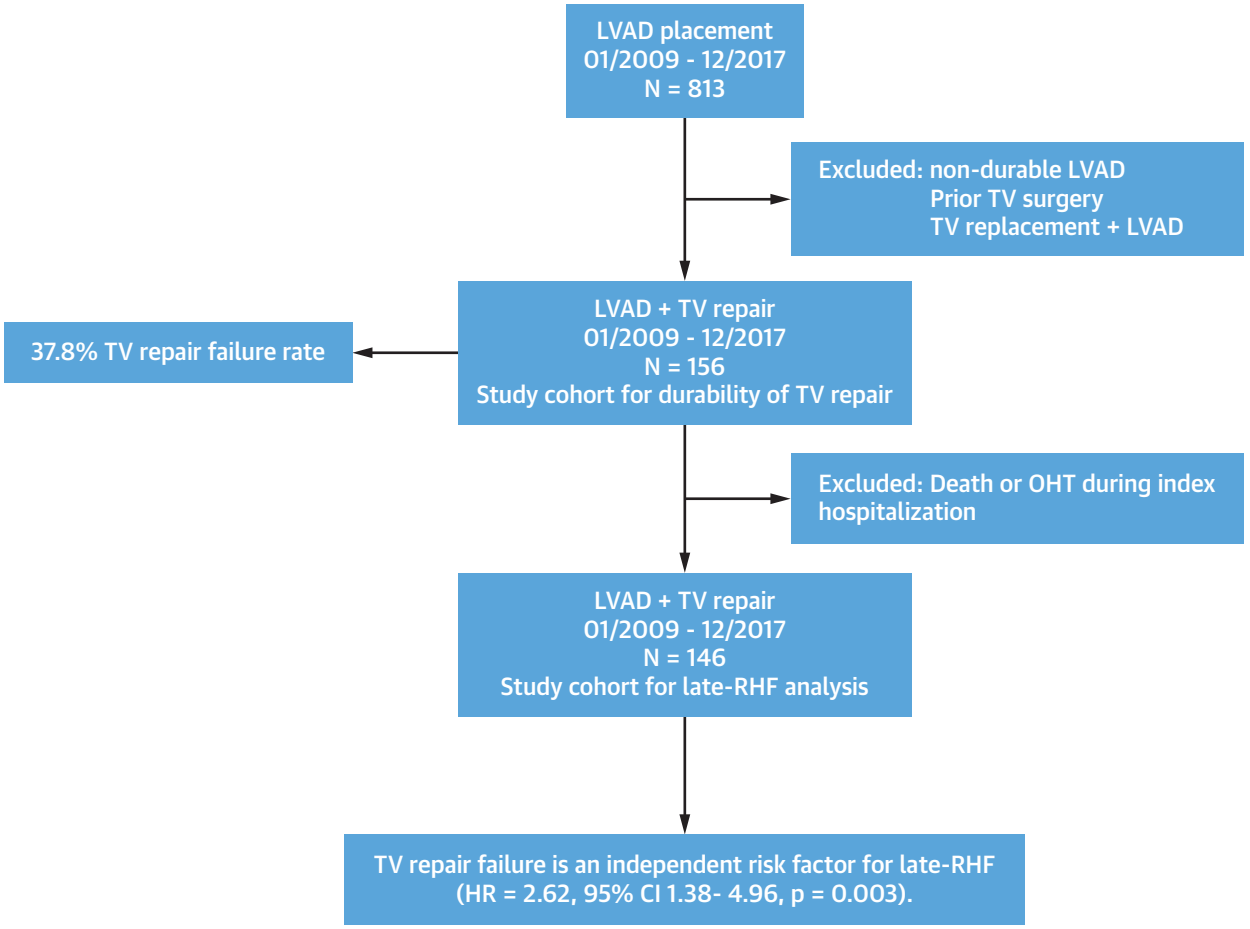
CI = confidence interval; HR = hazard ratio; other abbreviations as in Table 1.

FIGURE 3 Time to RHF Readmission



Time to right heart failure readmission stratified by TVr failure (log rank p < 0.001). RHF = right heart failure; other abbreviations as in Figures 1 and 2.

CENTRAL ILLUSTRATION Graphic Abstract



Barac, Y.D. et al. J Am Coll Cardiol HF. 2019;■(■):■–■.

Graphic abstract describes the study cohort and main findings of the study. CI = confidence interval; HR = hazard ratio; LVAD = left ventricular assist device; OHT = orthotopic heart transplantation; RHF = right heart failure; TV = tricuspid valve.

The cause for the TR recurrence in these cases is not well understood. Use of smaller rings had been suggested as a strategy to increase repair durability in cases of functional atrioventricular valve regurgitation, but the annuloplasty ring sizes used in 73% of the present study patients were the second smallest size (28 mm) or the smallest sized ring (26 mm), suggesting that ring size reduction may not prevent the failures. Furthermore, the smaller ring size may result in a significant diastolic pressure gradient across the valve. An analogous observation of reduced durability has been reported with ischemic mitral valve regurgitation, which was treated with use of undersized annuloplasty alone (24). Together these observations suggest that bioprosthetic replacement of the valve should be considered, in some cases, to achieve greater freedom from recurrence of TR, and the subpopulations that may benefit from a replacement strategy should be investigated in the future.

Determination of the clinical benefit of concurrent TV procedures will require a prospective randomized trial, but the data from the present study would caution against annuloplasty repair alone as the concurrent procedure because there is substantial recurrence, and recurrence may be impacting clinical outcome.

STUDY LIMITATIONS. Important limitations of this report include nonprotocolized echocardiographic follow-up. Although echocardiographic studies have

been interpreted and reported by attending cardiologists and cardiac anesthesiologists, the grading of TR severity relied on multiple readers, which could have reduced uniformity. Furthermore, TR severity may have been impacted by loading condition, RV dysfunction, and medical strategies such as diuretic agents and pulmonary vasodilators, which may have not been uniformly applied to all subjects. The authors also must acknowledge the fact that RV dysfunction in the follow-up period might have played a role in the clinical presentation of the patients and might have preceded TVr failure. However, there were no differences in RV function pre-LVAD implantation between the 2 study groups, and TVr failure was diagnosed in 86% of the patients before or at the indexed hospitalization for late-RHF. Although pump failure due to thrombosis or inflow cannula or outflow graft obstruction was excluded as 1 of the causes for readmission, suboptimal function of the LVAD cannot be excluded as there is no reliable information regarding pump parameters at the time of readmission. Finally, some patients underwent cardiac transplantation or died of non-heart failure causes, which may have interfered with assessment of TV repair failure.

CONCLUSIONS

In the present large cohort of patients undergoing ring annuloplasty TVr concurrent with LVAD implantation, the authors demonstrated that, in intermediate follow-up, the rate of recurrence was 37.8% and that failure of TVr was independently associated with the development of late RHF. The findings of this study add to the limited existing data regarding the durability of TV repair and its impact on clinical outcomes in this patient population. Furthermore, randomized studies may be required to determine the clinical benefit of concurrent TV procedures and may help to identify specific sub populations that may benefit from a replacement strategy (**Central Illustration**).

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: TV repair performed concurrently with LVAD implantation results in a high percentage of repair failure and is independently associated with the development of late RHF.

TRANSLATIONAL OUTLOOK 1: TV repair failure occurred regardless of using an undersized ring. Future studies should identify predictors for TV repair failure and subpopulations that might benefit from valve replacement.

TRANSLATIONAL OUTLOOK 2: TV repair failure was independently associated with late RHF. Future randomized studies should investigate the benefit of TV repair.

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