

Unplanned Hospital Readmissions After HeartMate II Implantation

Frequency, Risk Factors, and Impact on Resource Use and Survival

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- Objectives** The purpose of this study was to identify potential areas for quality improvement and cost containment. We investigated readmissions after HeartMate II left ventricular assist device (LVAD) implantation by characterizing their type, temporal frequency, causative factors, and resource use and survival after readmission.
- Background** The HeartMate II LVAD provides enhanced survival and quality of life to end-stage heart failure patients. Whether these improved outcomes are accompanied by a similar reduction in unplanned hospital readmissions is largely unknown.
- Methods** From October 2004 to January 2010, 118 patients received a HeartMate II, of whom 92 were discharged on device support. Subsequent readmissions were analyzed using prospectively maintained clinical and financial databases.
- Results** Forty-eight patients (52%) had 177 unplanned hospital readmissions, 87 non-LVAD- and 90 LVAD-associated. Reasons for non-LVAD-associated readmissions included medical management of comorbidities and progression of cardiac pathology (n = 48), neuropsychiatric/psychosocial issues (n = 22), and infections (n = 17). Those for LVAD-associated readmissions included device component infection (n = 51), management of nontherapeutic anticoagulation or device malfunction (n = 22), and bleeding (n = 15). Cumulative incidence of unplanned readmissions was higher (p < 0.0001) for destination therapy than bridge-to-transplant patients (9/patient vs. 4/patient at 24 months). Cumulative hospital days overall were 25 and 42 at 12 and 18 months, respectively, and the costs were 18% and 29% of initial implantation costs. Increased number of unplanned readmissions was predictive of mortality.
- Conclusions** Unplanned readmissions are common during HeartMate II support and negatively affect resource use and survival. Refining patient selection, especially in destination therapy patients, reducing infectious and bleeding complications, and increasing awareness about these devices might reduce unnecessary readmissions. (J Am Coll Cardiol HF 2013;1:31-9) © 2013 by the American College of Cardiology Foundation

Progression of underlying cardiac disease and noncardiac comorbidities, infections, device malfunctions, and transplantation all precipitate both planned and unplanned hospital readmissions after implantation of durable ventricular assist devices (1-3). The nature of these readmissions—frequency,

etiology, resource use, and prognostic implications—remains largely unknown. With mounting efforts to maximize efficiency and limit unnecessary consumption of healthcare resources, readmissions associated with mechanical circulatory support face increasing scrutiny. To identify potential areas for quality improvement and cost containment, we investigated readmissions after HeartMate II left ventricular assist device (LVAD) implantation by characterizing their type, temporal frequency, causative factors, appropriateness, and resource use and survival after readmission (4).

Methods

Patients. From October 2004 to January 2010, 118 patients 18 years of age or older with end-stage heart failure underwent first-time HeartMate II LVAD implantation at

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**Abbreviations
and Acronyms****BTT** = bridge to
transplantation**LVAD** = left ventricular
assist device**RBC** = red blood cell

Cleveland Clinic. The indications were bridge to transplantation (BTT) (most patients; $n = 98$) and destination therapy ($n = 20$). For purposes of this paper, BTT patients included all Interagency Registry for Mechanically Assisted Circulatory Support (INTER-

MACS) categories of bridged patients, not simply those listed for transplantation. Among these patients, 16 died and 10 underwent cardiac transplantation during their initial hospital stay. Thus, 92 were discharged on device support and were at risk for hospital readmission.

Data. Clinical data were extracted from the Electronic Data Interface for Transplant and Cardiovascular Information Registry and the Cleveland Clinic Financial Database. These registries are approved for use in research by the Institutional Review Board, with patient consent waived. Individual hospital and outpatient medical records were reviewed for data confirmation and adjudication of details concerning readmissions. Demographic data and clinical characteristics of LVAD implantation are presented overall and separately for the BTT and destination therapy patients in [Table 1](#).

Endpoints. The primary endpoint was all-cause hospital readmission. Hospital readmissions were first categorized as planned versus unplanned. Planned readmissions included cardiac transplant and elective non-LVAD-associated procedures. Unplanned readmissions were then categorized as LVAD-associated or non-LVAD-associated. Non-LVAD-associated unplanned readmissions were then categorized into 4 broad groups:

- Management of noncardiac comorbidities
- Management of cardiac disease progression
- Management of neuropsychiatric/psychosocial issues
- Management of non-LVAD-associated infections

Secondary endpoints were:

- Unplanned readmission length of stay (days)
- Direct technical cost (not charges) of each unplanned readmission indexed to median direct technical cost of initial device implant (cost of device and of all hospital costs from date of implant to initial hospital discharge)
- Death after initial hospital discharge, categorized as death on mechanical circulatory support before transplantation or device removal and death after readmission
- Cardiac transplantation or device removal (censoring events)

By INTERMACS criteria (5), patient follow-up schedule after device implantation is 1 week, 1, 3, and 6 months, and every 6 months thereafter. As of July 1, 2010, for the 92 patients at risk of readmission, mean follow-up was 1.3 ± 0.47 years (median = 1.2, 15th percentile = 0.83, 85th percentile = 1.9 years) from date of initial discharge. Ten percent of the survivors were followed more than 2 years; none

was lost to follow-up. A total of 111 patient-years of data during HeartMate II support were available for analyses.

Data analysis. SAS software (SAS Institute, Inc., Cary, North Carolina) was used for data analysis. For all analyses, “time zero” was date of discharge from the hospital after LVAD implant.

TIME-RELATED EVENTS ANALYSIS. Because patients can be readmitted more than once during follow-up, and each readmission is of varying duration and cost, we used analytic methods for repeated, weighted, time-related events rather than traditional time-to-first-event (survival) analysis. Therefore, patients remain at risk for another event after experiencing an event, unlike with survival-type analysis.

Cumulative number of readmissions/patient across time was estimated by Nelson’s nonparametric method (6). This method accounts for censoring at LVAD removal (pump exchange, death, transplantation) or end of follow-up without experiencing these. Thus, only the first device implanted is tracked in our analysis. Instantaneous risk (hazard function) of repeated readmissions was estimated by the parametric method of Blackstone *et al.* (7) (for additional details, see Cleveland Clinic’s Hazard Function Technology website [8]). This method is useful for possibly complex time-varying hazard by decomposing it into as many as 3 mathematically simple components, called phases. Because the method is similar to Fourier analysis, which breaks white light into its component colors, each phase can accommodate possibly different risk factors (nonproportional hazards), unlike traditional Cox proportional hazards models. The number of phases present in a given set of event-time pairs is determined by the likelihood ratio test with a given phase in and out of the model using a p value criterion of 0.05. The specific equation characterizing each of the 2 nonconstant hazard phases is determined by values for shaping parameters possibly going to 1 or infinity, with a p value criterion of 0.05. Our strategy was to select the simplest model with log-likelihood not significantly worse than a saturated model.

Nelson’s method and the parametric method account for duration of each readmission as a so-called weighted event (9). Thus, the cumulative number of hospital days/patient across time can be calculated as well as the rate (hazard) of accumulating those days. Nelson’s original work associated a cost with an event, calling it the cumulative cost function. We also analyzed indexed readmission costs, using his and the parametric method, presenting them as cumulative indexed cost/patient across time and the rate of accumulating cost. As will be seen, unlike readmissions that increment cumulative graphs by single units (normalized to number at risk), both hospital days and costs increment then by highly variable amounts.

Time-related mortality while on support was analyzed similarly, except that the Kaplan-Meier estimator was used rather than the Nelson nonparametric method.

MULTIVARIABLE ANALYSES. Because of the nonproportional hazards nature of readmissions, duration of readmissions,

Table 1 Patient Characteristics and Peri-Operative Details

Characteristic	n*	All Patients (n = 92)	n*	BTT (n = 78)	n*	DT (n = 14)	p Value†
Demographics							
Age (yrs)	92	53 ± 14	78	52 ± 14	14	60 ± 14	0.03
Male	92	72 (78)	78	61 (78)	14	11 (78)	>0.9
Body mass index (kg/m ²)	92	27 ± 6.0	78	28 ± 6.0	14	24 ± 5.0	0.012
Noncardiac comorbidity							
Hypertension	92	48 (52)	78	40 (51)	14	8 (57)	0.7
Diabetes	92	35 (38)	78	29 (37)	14	6 (43)	0.7
COPD	92	12 (13)	78	7 (9.0)	14	5 (36)	0.006
Tracheostomy	92	1 (1.1)	78	1 (1.3)	14	0 (0)	>0.9
Dialysis	92	5 (5.4)	78	5 (6.4)	14	0 (0)	0.3
Bilirubin (mg/dl ¹)	88	1.3 ± 1.1	75	1.3 ± 0.89	13	1.5 ± 1.9	0.3
Albumin (g/dl ¹)	88	3.5 ± 0.62	75	3.5 ± 0.63	13	3.5 ± 0.57	0.6
Creatinine (mg/dl ¹)	90	1.4 ± 0.56	76	1.4 ± 0.57	14	1.5 ± 0.51	0.5
Blood urea nitrogen (mg/dl ¹)	76	35 ± 21	65	34 ± 21	11	42 ± 17	0.06
Aspartate transaminase (U/l ¹)	71	21/36/90	62	21/37/95	9	21/29/54	0.4
Alanine transaminase (U/l ¹)	71	16/37/100	62	15/41/141	9	15/21/46	0.05
Life support							
ECMO	92	9 (9.8)	78	8 (10)	14	1 (7.1)	0.7
IABP	92	28 (30)	78	25 (32)	14	3 (21)	0.4
Inotropic therapy	92	56 (61)	78	53 (68)	14	3 (21)	0.001
Ventilator	92	12 (13)	78	10 (13)	14	2 (14)	0.9
Intra- and post-operative blood product use							
Packed RBCs	90	4/10/22	76	4/9/22	14	6/12/28	0.6
Platelets	90	2/4/8	76	2/4/8	14	2/4/7	0.8
Fresh frozen plasma	90	5/12/18	76	5/12/18	14	6/12/19	0.8
Time intervals							
Admission to implant (days)	92	3/10/20	78	3/10/24	14	0/8/17	0.4
Post-implant ICU length of stay (days)	91	5/9/16	77	5/9/16	14	4/10/19	0.7
Implant to initial discharge (days)	92	23/36/52	78	22/35/49	14	28/46/65	0.02

Values are n (%), mean ± SD, or 15th/50th/85th percentiles. *Patients with data available. †Bridge to transplant (BTT) versus destination therapy (DT).

COPD = chronic obstructive pulmonary disease; ECMO = extracorporeal membrane oxygenation; IABP = intra-aortic balloon pumping; ICU = intensive care unit; RBCs = red blood cells.

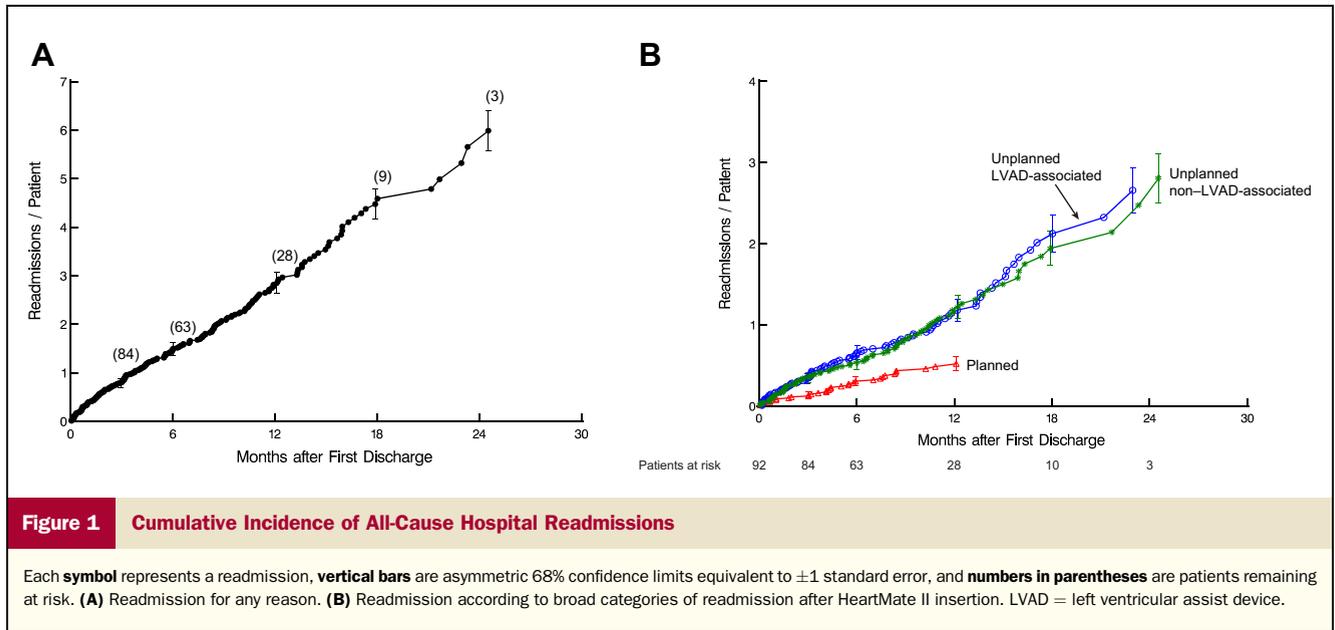
indexed cost of readmissions, and mortality, the same set of variables was considered in each resolved hazard phase during multivariable analysis (see [Online Appendix 1](#) for the list of variables considered). Because results of a single multivariable analysis can be unstable, variable selection used bootstrap aggregation (bagging) (10,11). Briefly, a dataset was constructed of size equal to the original by random sampling of cases with replacement (bootstrap sampling). On average, approximately one-third of patients are not picked, whereas some patients are selected more than once. The bootstrap sample was analyzed by an automated forward stepwise algorithm with an entry criterion of $p < 0.1$ and a retention criterion of $p < 0.05$. The result was stored. This process of sampling, automated analysis, and storing was repeated 500 times. During such analyses, the signal appears stronger and stronger with each successive analysis (12,13). When completed, the number of times a variable appeared in these 500 analyses was taken as a reflection of reliability (signal). Following Breiman's median rule, we retained variables appearing in at least 50% of the models, with the interpretation that there is at least a 50% chance the variable is statistically significant ($p < 0.05$).

Because a priori certain sets of variables are highly correlated, such as height, weight, body surface area, and body mass index,

post-processing of the 500 bootstrap analyses was performed over a cluster of such variables (each such cluster is identified in the [Online Appendix 2](#)), which not only indicated the reliability of the cluster but also the number of members of the cluster usually present in the models—generally 1—and the identity of the most commonly occurring representative of the cluster. This variable was selected for inclusion in the final model. In addition, to conform with linearity assumptions of the model, a set of transformations of scale for continuous variables was incorporated into the bagging process. The cluster of transformations was aggregated, the reliability of the cluster was determined, and the number of transformations generally appearing in the models (for example, a U-shaped relationship to risk would typically require 2 transformed variables) and the most commonly appearing transformation (or pairs of transformations) were identified for inclusion in the final model.

At the conclusion of the bagging process, a final model was formed from the bagged results.

Readmission was treated as a time-varying covariable for both subsequent readmissions in repeated-events analyses and in the analysis of death. Four variables relating to each readmission were analyzed: 1) readmission (yes/no); 2) sequence number of each readmission; 3) interval between time zero and the previous readmission; and 4) interval since last readmission.



MISSING VALUES. Multiple imputation was used to provide sporadic missing values for covariables rather than eliminating patients from any analysis. Missing values are identified in Table 1. For this, 5-fold multiple imputation was performed (14) with a Markov Chain Monte Carlo technique (SAS PROC MI, version 9.1, SAS, Inc.). Only covariables were imputed, not outcomes. Bootstrap bagging for variable selection, as described earlier, used 1 imputed dataset. Regression coefficients and their variance–covariance matrix for the final models were subsequently estimated for each imputed dataset and combined (PROC MIANALYZE, version 9.1, SAS, Inc.) using the method of Rubin (14) to produce the final estimates.

Presentation. Continuous variables are summarized by mean \pm SD or median and equivalent 15th and 85th percentiles for skewed data. Categorical variables are summarized by frequencies and percentages. Uncertainty is expressed by 68% confidence limits, comparable to ± 1 standard error.

Results

Hospital readmissions. Of 92 HeartMate II patients discharged after initial implantation, 72 (78%) were readmitted a total of 211 times as of end of follow-up. Cumulative number of readmissions/patient for any reason was 0.35, 0.79, 1.45, 2.8, and 4.5 at 1, 3, 6, 12, and 18 months, respectively (Fig. 1A). Of these, 177 were unplanned in 48 patients (Fig. 1B). Most (74%) of the 34 planned readmissions were for cardiac transplantation ($n = 25$) or other elective procedures.

Unplanned readmissions. Forty-eight patients (52%) had unplanned hospital readmissions. Cumulative number of unplanned readmissions/patient was 0.26, 0.65, 1.15, 2.3, and 3.8 at 1, 3, 6, 12, and 18 months, respectively (Online Figs. 1A and 1B). After an early high risk of readmission,

readmissions leveled off to approximately 20%/month (Online Fig. 1C). Thirty-four patients were readmitted at least twice; 1 patient had 16 readmissions.

Reasons for unplanned readmissions. Of the unplanned readmissions, 87 (49%) were non-LVAD-associated (Fig. 2A, Table 2), and 90 were LVAD-associated (Fig. 2B, Table 2).

Reasons for non-LVAD-associated readmissions, in order of frequency, were:

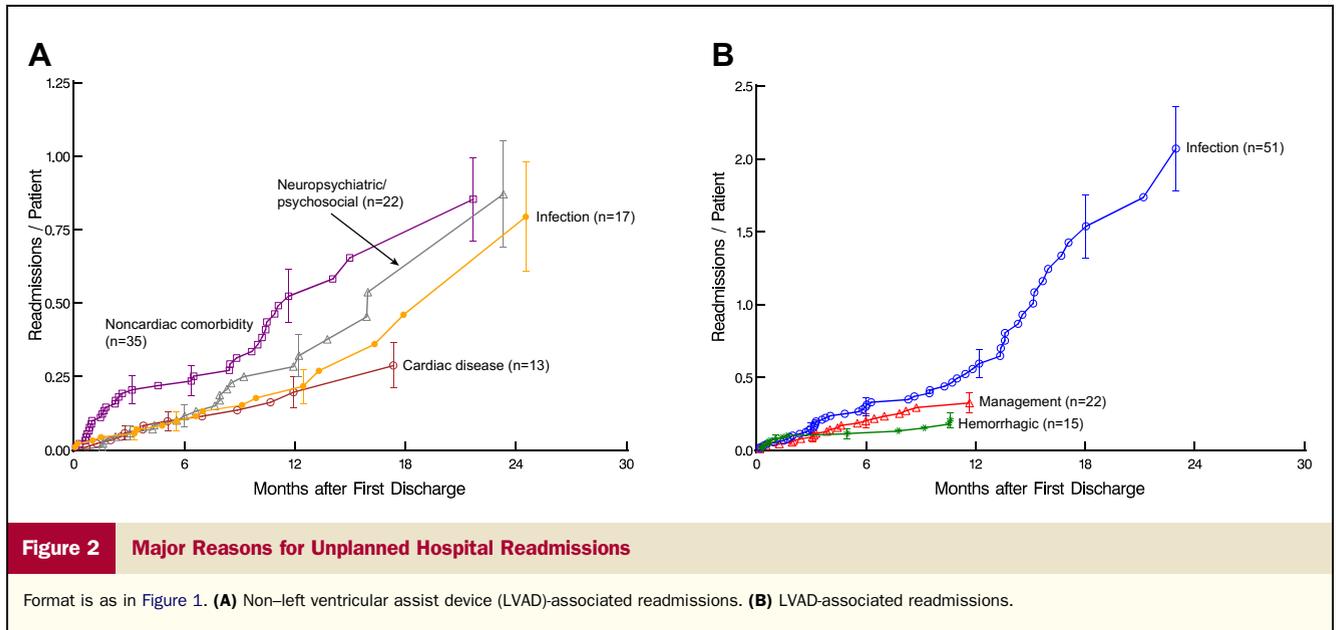
- Management of noncardiac comorbidities ($n = 35$)
- Management of neuropsychiatric/psychosocial issues ($n = 22$)
- Management of infections ($n = 17$)
- Management of cardiac disease progression ($n = 13$)

Reasons for LVAD-associated readmissions, in order of frequency, were:

- Management of infection ($n = 51$)
- LVAD management ($n = 22$)
- Bleeding complications ($n = 15$)
- Patient–LVAD interface complications ($n = 2$)

Readmission for medical management started shortly after initial discharge (Fig. 2B).

Risk factors for unplanned hospital readmissions. Destination therapy patients had a higher risk of unplanned readmissions, particularly early after the hospital stay for LVAD implantation, compared with those in whom the device was intended as a BTT (Fig. 3, Table 3). Destination therapy patients seemed to have a greater frequency of LVAD-associated hemorrhage and management readmissions (Fig. 4A). For non-LVAD-associated readmissions, destination patients experienced higher frequency of medical management and infection-related readmissions (Fig. 4B). Of the 48 patients with unplanned readmissions, 96% had at least 2 U of packed red blood cells (RBCs)



transfused intraoperatively; as number of units transfused increased, risk of unplanned readmission rose (Online Fig. 2). The relationship between blood urea nitrogen and unplanned readmissions was nonlinear, with both extremes being risk factors (Online Fig. 3). Patients who were not receiving inotropes pre-operatively (56%) were at higher risk of unplanned readmissions (Online Fig. 4). Readmissions seemed to be overall independent of any prior readmission.

Resource use. Cumulative number of hospital days associated with unplanned readmissions was 3.8, 8.1, 13, 25, and 42 at 1, 3, 6, 12, and 18 months, respectively (Online Figs. 5A and 5B). Overall, hospital days accumulated more rapidly in the first 30 to 45 days after the hospital stay for LVAD implantation and thereafter accumulated approximately 2 days/month (Online Fig. 5C). However, duration of hospital stay accelerated after 12 months for LVAD-associated readmissions compared with non-LVAD-associated readmissions (Fig. 5A). Direct technical costs of these readmissions were 2.2%, 5.0%, 9.6%, 19.5%, and 30% of initial implant cost at 1, 3, 6, 12, and 18 months, respectively (Online Figs. 6A and 6B). Overall, costs accumulated rapidly for the first 6 months before relative costs leveled out at approximately 1.8% of initial implantation cost/month. Higher pre-LVAD creatinine level was also a risk factor (Table 4). However, costs of readmissions also accelerated after 12 months for LVAD-associated readmissions (Fig. 5B).

Survival and unplanned readmissions. Survival on the HeartMate II decreased with each unplanned hospital readmission (adjusted $p = 0.002$) (Fig. 6, Online Figs. 7A to 7C). Higher pre-LVAD creatinine level was also a risk factor (Table 4).

Discussion

Principal findings of this study of predominantly BTT patients were that most discharged HeartMate II patients

had 1 and often multiple unplanned readmissions within the first year, and resource use for each unplanned LVAD-associated readmission increased rapidly after 12 months. Furthermore, we found a novel link between greater number of unplanned readmissions and increased risk of death during mechanical circulatory support. Increased creatinine at the time of initial HeartMate II implantation, a marker for more advanced end-organ dysfunction and hypoperfusion, was also predictive of increased mortality.

Frequency and indications for readmission. The proportion of readmissions that were unplanned, 52%, is similar to reported proportions of 55% to 68% (15,16). This frequency underestimates the potential healthcare burden of readmissions, because death is a competing outcome. As more patients survive implantation, readmissions will become an increasingly important quality metric. To date, the only published report to systematically quantify HeartMate II readmissions and itemize their indications emerged from the Johns Hopkins group (3). That analysis included only 23 HeartMate II patients surviving 1 year after implantation. The leading indications for readmission were infection (43%) and hemorrhagic complications (20%), as with the present study. The infectious sources were predominantly (in decreasing order) driveline, bloodstream, and LVAD pocket. The investigators calculated, on the basis of the observed 3 admissions/year on mechanical circulatory support at <2 weeks/admission, that more than 87% of support days were spent outside the hospital. This might be true, but the present analysis indicates that—for a large subset of patients—increasing duration of support (1 year and beyond) translates into a greater likelihood of numerous, resource-intensive, unplanned readmissions.

Risk factors for readmissions. Destination therapy patients were more likely to have unplanned readmissions, and the reasons differed from BTT patients with respect to patient management issues related to treating comorbid

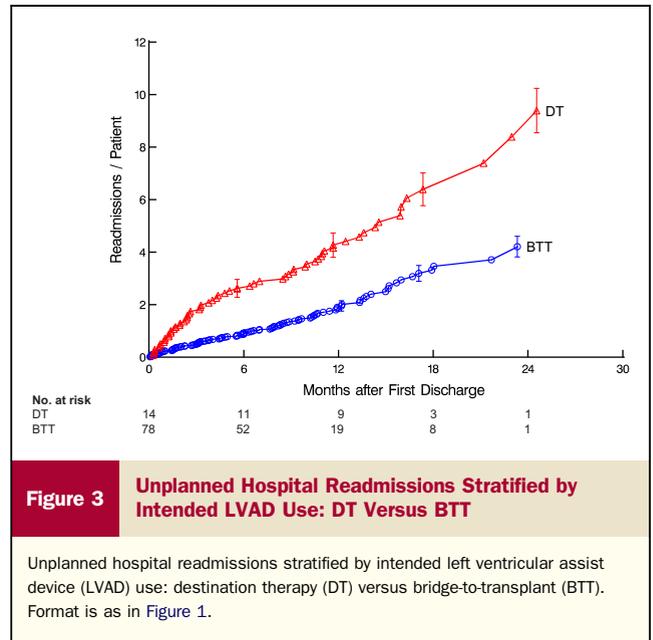
Table 2 Reasons for Unplanned Hospital Readmissions

Non-LVAD-associated	
Management of noncardiac comorbidities	
Gastrointestinal*	11
Musculoskeletal	6
Volume optimization	5
Anemia	3
Hepatic decompensation	2
Hypertension	2
Noncardiac respiratory	2
Trauma	2
Carpal tunnel syndrome	1
Other	2
Management of cardiac disease progression	
Right heart failure	7
Ventricular tachycardia	4
Atrial fibrillation	2
Management of neuropsychiatric/psychosocial issues	
Medical noncompliance	16
Anxiety/depression	2
Substance abuse	2
Mental status changes	1
Management of infections	
Urinary tract	7
Fever of unknown origin	4
Sepsis	2
Skin	2
Gastrointestinal sepsis	2
LVAD-associated	
Management of infections	
Driveline	28
Pump pocket	10
Pump septic emboli	4
Pump sepsis	3
Superficial sternal wound	3
Urinary tract	1
Pleurocutaneous fistula	1
Line sepsis	1
LVAD management	
Supratherapeutic international normalized ratio	8
Pump optimization	5
Pump thrombosis	5
Other	4
Management of hemorrhagic complications	
Gastrointestinal	12
Cerebral	3
Patient-LVAD interface	
Inadvertent controller disconnect	1
Fractured driveline	1

Values are n. *Nausea, vomiting, diarrhea, and so forth.
LVAD = left ventricular assist device.

conditions. Surprisingly, non-LVAD-related infections increased at a steady rate throughout the study. The mechanisms for this remain largely unknown but might reflect the overall frailty of destination therapy patients (17).

Repeatedly, RBC transfusions have been shown to be associated with reduced survival and increased number of infections, and in our study, were associated with readmission.



The mechanism is unknown but could be related to increased non-LVAD-related infections in the destination therapy cohort and driveline infections in the entire cohort. In a recent study by Schaffer et al. (18) from Johns Hopkins, RBC transfusion was an important predictor of mortality after implantation of 86 continuous-flow LVADs. The total amount of blood products transfused within the first week of device implantation averaged 15.6 U, closely approximating the quantity noted in the present study. Although increased RBC transfusion was not directly predictive of mortality in our study, it did portend subsequent unplanned readmissions that were associated with reduced survival. Others have also documented the negative impact of increased RBC transfusions during HeartMate II support, as evidenced by significantly diminished 1-year survival after subsequent cardiac transplantation (19).

We are puzzled by the association between absence of pre-operative inotropes and increased readmissions. We could not find a link between no inotropic therapy and

Table 3 Incremental Risk Factors for Unplanned Readmissions

Factors	Coefficient ± SE	p Value	Reliability (%)*
Early hazard phase			
None			
Late hazard phase			
Readmission interval	-2.84 ± 0.57	<0.0001	100
Blood urea nitrogen†	0.074 ± 0.019	<0.0001	87
Blood urea nitrogen‡	0.049 ± 0.014	0.0006	87
Increased intraoperative RBC units transfused§	0.036 ± 0.012	0.004	57
Destination therapy	0.95 ± 0.21	<0.0001	79
Pre-operative inotropes	-0.82 ± 0.22	0.0001	68

*Percentage of times factor appeared in 500 bootstrap models. †(Exp[blood urea nitrogen]), exponential transformation. ‡(Blood urea nitrogen/35)², inverse squared transformation. §(Red blood cells [RBCs]/12)², squared transformation.

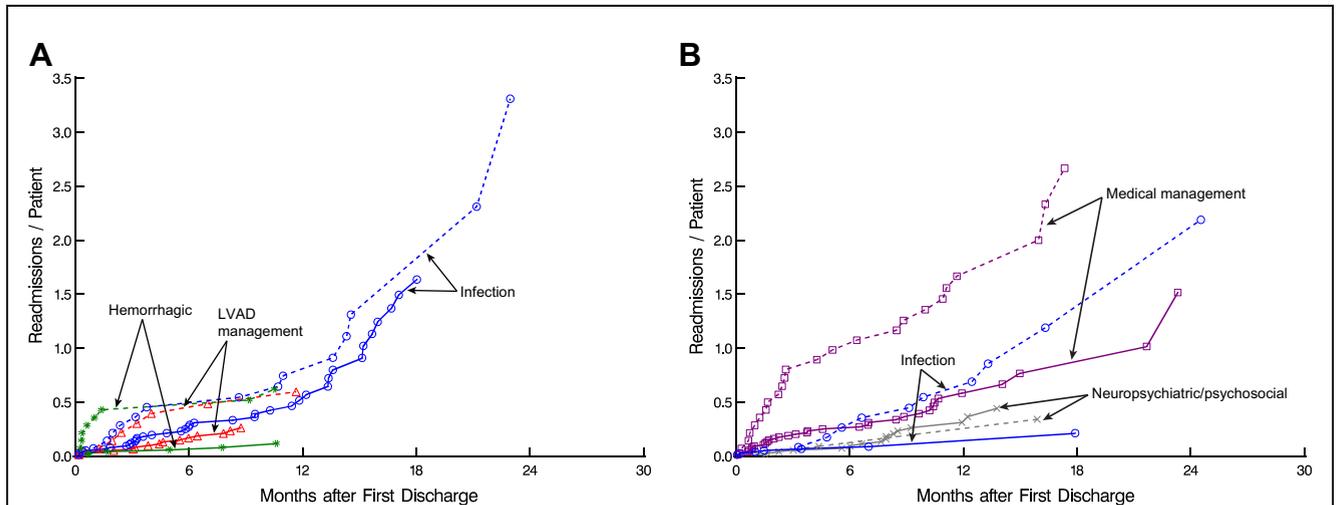


Figure 4 Reasons for Unplanned Hospital Readmissions According to Intended LVAD Use: DT or BTT

Reasons for unplanned hospital readmissions according to intended LVAD use: DT (dashed lines) or BTT (solid lines). Format is as in Figure 1. Each symbol represents a readmission. (A) LVAD-associated reasons. (B) Non-LVAD-associated reasons. Abbreviations as in Figure 3.

destination therapy, speculating that perhaps elective outpatient destination therapy patients who were older with more comorbidities were not receiving inotropes. Another relationship we examined is the possibility that the acutely ill patients receiving extracorporeal membrane oxygenation or intra-aortic balloon pump support might have had inotropes discontinued, and because of this critical state, were more likely to require readmission after discharge. This was not the case, and the mechanism remains unexplained.

Resource use. Cumulative readmissions are much more costly for device-related readmissions, reflecting the need for more intensive management, diagnostic testing, and repeated surgical intervention. Driveline-related and pump-pocket infections account for the majority of LVAD-associated readmissions and are essentially incurable, explaining the inexorable rise in cost per patient. Occurrence of device-related infections can be attenuated by avoiding trauma, strict adherence to sterile techniques, and

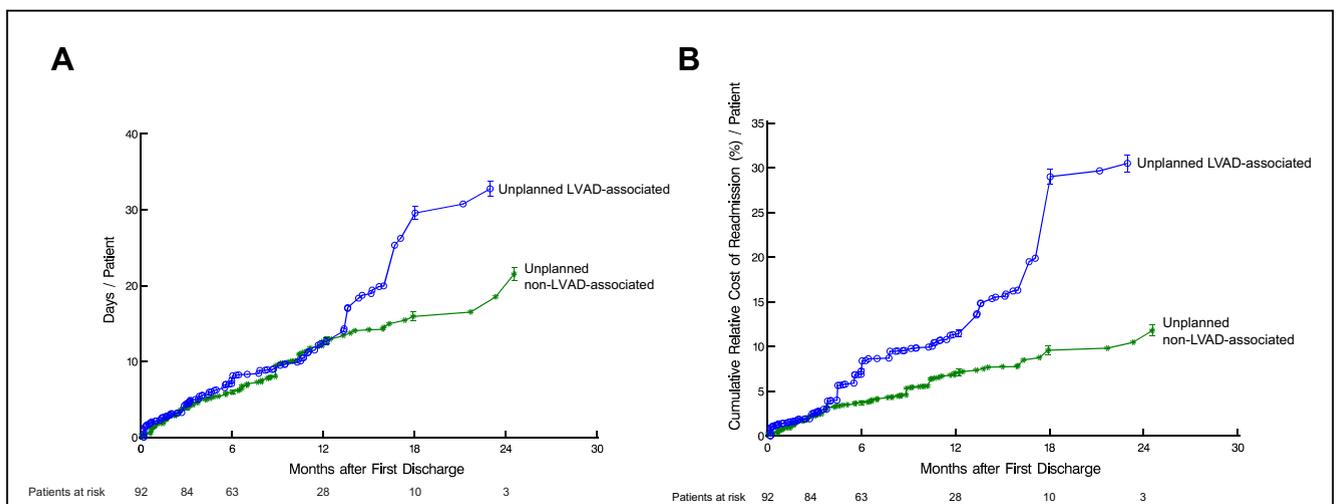


Figure 5 Cumulative Duration and Costs of Readmissions

Cumulative duration and costs of readmissions after HeartMate II implantation according to broad categories of unplanned readmission. Format is as in Figure 1. (A) Cumulative duration of hospital readmissions. (B) Cumulative direct technical cost of readmission indexed to initial implant costs. LVAD = left ventricular assist device.

Table 4 Incremental Risk Factors for Death

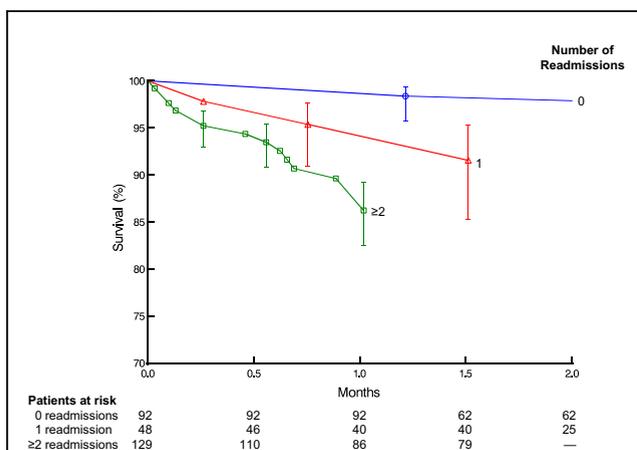
Factors	Coefficient ± SE	p Value	Reliability (%)*
Early hazard phase			
Higher number of readmissions (renewal-1)	0.77 ± 0.29	0.01	55
Late hazard phase			
Higher number of readmissions (renewal-1)	0.37 ± 0.094	<0.0001	63
Interval: previous readmission to death (yrs)	-29 ± 12	0.01	66
Higher serum creatinine (mg/dl ¹)	1.31 ± 0.39	0.001	69

*Percentage of times factor appeared in 500 bootstrap models.

meticulous wound care (20,21). Ultimately, a completely implantable system, which is likely to be initially more expensive than current technology, might be the most cost-effective option.

Survival. This study demonstrates a linkage between readmissions and survival. It provides an example of the complex relationship between readmission and mortality when they are medically interdependent. These data and our evaluation of timing of transplantation after LVAD implantation suggest that a shorter period of mechanical circulatory support would reduce both readmissions and death on support (22).

Reducing readmissions. Outpatient management of patients receiving mechanical circulatory support is time intensive and requires a multidisciplinary approach. Our team includes cardiologists, cardiac surgeons, infectious disease and other medical subspecialists, LVAD coordinators, social workers, financial counselors, and research nurses. Together, we have developed several strategies directed at reducing unplanned readmissions in the LVAD population.

**Figure 6** Conditional Survival After Each Unplanned Hospital Readmission

To construct graph, patients were censored at readmission, and survival was again assessed starting at a new time zero. Format is as in Figure 1.

First, we believe that successful long-term care must begin pre-operatively, with assessment of patient cognitive abilities, support systems, and home environment. Second, device education and self-care instructions are begun before surgery and are continuously reinforced. Third, once discharged, patients return to the outpatient clinic weekly for the first month and undergo a full history and physical examination and driveline examination in particular, plus medication reconciliation, echocardiography, radiography, laboratory work, and a visit with a social worker to address nonmedical concerns. Fourth, patients are entered into a cardiac rehabilitation program and then progress to monthly and then bi-monthly outpatient visits. Telephone contact occurs frequently to address anticoagulation as well as other non-LVAD-related issues. Finally, we continuously communicate with the primary care physician of the patient.

Study limitations. A primary limitation of this study is the single-center clinical cohort design. The number of patients in the present study is relatively small, in comparison with multi-institutional studies of outcomes after HeartMate II implantation, but the advantage is more detailed characterization of each readmission, including its fiscal impact. Formal longitudinal self-assessment of quality of life would have added an important patient perspective, but was not performed.

Conclusions

Similar to mortality, readmissions during mechanical circulatory support are related to pre-operative patient characteristics, adverse events occurring during support, and increasing duration of support. As with the care of heart failure patients in general, increased awareness of care protocols by primary care physicians and heart failure specialists and novel community and home-based therapies are needed to reduce readmissions and the services consumed by patients receiving mechanical circulatory support.

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Key Words: heart failure ■ left ventricular assist devices ■ mechanical circulatory support.

 **APPENDIX**

For supplemental material, please see the online version of this article.