Thirty-Day Readmissions After Left Ventricular Assist Device Implantation in the United States: Insights From the Nationwide Readmissions Database.

Sahil Agrawal
St. Luke's Health System

Lohit Garg MD
Lehigh Valley Health Network, lohit.garg@lvhn.org

Mahek Shah MD
Lehigh Valley Health Network, Mahek.Shah@lvhn.org

Manyoo Agarwal
University of Tennessee

Brijesh Patel MD
Lehigh Valley Health Network, brijesh.patel@lvhn.org

See next page for additional authors

Published In/Presented At

Agrawal, S., Garg, L., Shah, M., Agarwal, M., Patel, B., Singh, A., Garg, A., Jorde, U. P., & Kapur, N. K. (2018). Thirty-Day Readmissions After Left Ventricular Assist Device Implantation in the United States: Insights From the Nationwide Readmissions Database. *Circulation. Heart failure*, *11*(3), e004628. https://doi.org/10.1161/CIRCHEARTFAILURE.117.004628

Authors

Sahil Agrawal, Lohit Garg MD, Mahek Shah MD, Manyoo Agarwal, Brijesh Patel MD, Amitoj Singh, Aakash Garg, Ulrich P Jorde, and Navin K Kapur

ORIGINAL ARTICLE

Thirty-Day Readmissions After Left Ventricular Assist Device Implantation in the United States

Insights From the Nationwide Readmissions Database

Sahil Agrawal, MD*
Lohit Garg, MD*
Mahek Shah, MD
Manyoo Agarwal, MD
Brijesh Patel, DO
Amitoj Singh, MD
Aakash Garg, MD
Ulrich P. Jorde, MD
Navin K. Kapur, MD

BACKGROUND: Early readmissions contribute significantly to heart failure–related morbidity and negatively affect quality of life. Data on left ventricular assist device (LVAD)–related 30-day readmissions are scarce and limited to small studies.

METHODS AND RESULTS: Patients undergoing LVAD implantation between January 2013 and November 2014 who survived the index hospitalization were identified in the Nationwide Readmissions Database. We analyzed the incidence, predictors, causes, and costs of 30-day readmissions. Of 2510 LVAD recipients, 788 (31%) were readmitted within 30 days. Length of index hospitalization ≥31 days (hazard ratio [HR], 1.26; 95% confidence interval [CI], 1.07–1.50) and female sex (HR, 1.19; 95% CI, 1.01–1.42) were associated with a higher risk of 30-day readmission, whereas private insurance (HR, 0.83; 95% CI, 0.70–0.99), pre-LVAD use of short-term mechanical circulatory support (HR, 0.53; 95% CI, 0.29–0.98), and discharge to a short-term hospital facility (HR, 0.41; CI, 0.21–0.78) were associated with a lower risk. Cardiac causes accounted for 23.8% of readmissions: heart failure (13.4%) and arrhythmias (8.1%). Noncardiovascular causes accounted for 76.2% of readmissions: infection (30.2%), bleeding (17.6%), and device-related causes (8.2%). Mean length of stay for readmission was 10.7 days (median, 6 days), and average hospital cost per readmission was $34 948±2457.

CONCLUSIONS: Early readmissions are frequent after LVAD implantation even in contemporary times. Preimplant identification of high-risk patients, and a protocol-driven follow-up using a multidisciplinary approach will be needed to reduce readmissions and improve outcomes.

*Drs Agrawal and Garg contributed equally to this work as co-first authors.

Correspondence to: Sahil Agrawal, MD, St. Luke's University Health Network, 801, Ostrum St, Bethlehem, PA 18015. E-mail sahilagrawal124@gmail.com

Key Words: heart-assist devices ■ heart failure ■ hospital costs ■ hospitalization ■ length of stay

WHAT IS NEW?

- Readmissions among advanced heart failure patients are common and contribute significantly to health care–related costs.
- Rates and causes of readmissions and their associated costs among patients with a durable left ventricular assist device have not been studied in a contemporary multi-institutional setting.
- The present study found that readmission rates among left ventricular assist device patients remain high and are mostly secondary to noncardiac causes.
- We identified female sex, nonprivate insurance, prolonged hospitalization during index admission, and discharge destination other than short-term hospital as independent predictors of 30-day readmission in this study population.

WHAT ARE THE CLINICAL IMPLICATIONS?

- Gastrointestinal bleeding and infections continue to be the most common causes of readmission in the left ventricular assist device population. Careful monitoring of anticoagulation and patient and caretaker education will be of paramount importance to curtail these adverse events.
- Predictors of readmissions as identified in our study would allow clinicians and heath professionals caring for these patients to identify those at the highest risk.
- More widespread availability of postdischarge ancillary care such as visiting nurses, patient educators, and rehabilitation services can be expected to positively impact readmissions.

Implantation of a continuous-flow left ventricular assist device (LVAD) improves survival and quality of life in patients with advanced end-stage heart failure (HF).[1] LVAD therapy is being increasingly used in an ever-growing population of HF patients, and is approved for destination therapy and bridge to heart transplantation indications.[2] Repeat hospitalizations contribute significantly to HF-related morbidity, negatively affect quality of life, and add significantly of healthcare costs.[3,4] Not surprisingly, repeat hospitalizations are used as a performance marker and are often included as a primary efficacy outcome in HF trials. As more patients survive to discharge after LVAD implantation, readmissions have become an increasingly important quality metric in this high-risk population of patients with a heavy burden of comorbidities. Like other patients with advanced HF, LVAD patients remain at high risk for readmission, with 30-day readmission rates of up to 30%.[5,6] Previous studies of LVAD-related readmissions are few and predominantly small, single-center experiences.[7,8] Further, no previous study has extensively studied the economic impact of such readmissions in this cost-intensive patient population. The main objective of this study is to determine the incidence, causes, and predictors of 30-day readmissions after implantation of a contemporary LVAD device using a large real-world nationally representative database of hospitalizations in the United States. Understanding these would help improve patient outcomes and reduce healthcare costs by identifying high-risk patients and implementing timely interventions.

METHODS

The data, analytic methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure.

Data Source

The study cohort was derived from the National Readmission Database (NRD) for years 2013 and 2014, which were the most recent data available at the time of inception of the study. The NRD is sponsored by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project (HCUP). Details on the NRD are available online.[9] In brief, the NRD is drawn from State Inpatient Databases that contain reliable, verified patient linkage numbers (indicated by variable NRD_visitlink) used to track a patient across hospitals within a state. The NRD includes data from 21 states that are geographically dispersed, and account for 49.3% of the total US resident population and 49.1% of all hospitalizations. HCUP partner states, which do not allow the release of patient-specific linkage numbers, are not included in the NRD, as this would not allow for analysis of readmission data. No fundamental differences between participating and nonparticipating states other than policy matters on privacy are anticipated. Discharge records of patients treated in US community hospitals excluding rehabilitation and long-term acute care facilities are included. All analysis was performed on unweighted data. This study was deemed exempt by the Institutional Review Board, as the NRD is a publicly available database containing deidentified patient information.

Study Population

Patients aged ≥18 years were identified as new LVAD recipients if their discharge record contained the *International Classification of Disease*, Ninth Revision; Clinical Modification (ICD-9-CM) procedure code 37.66 (corresponding to insertion of implantable heart assist system). This yielded an initial sample of 3164. Of these, patients who died during their index hospitalization (n=363, in-hospital mortality 11.5%) and those patients whose records were missing data on survival status (n=1) were excluded from readmission analysis. We further excluded patients who were discharged alive in December (n=290; because of lack of 30-day follow-up) yielding a final study population size of 2510.

Patient and Hospital Characteristics

Baseline patient characteristics included were age, sex, primary expected payer, median household income, relevant comorbidities (history of ischemic cardiomyopathy, ST-segment–elevation myocardial infarction at admission, cardiogenic shock during hospitalization, history of smoking, dyslipidemia, hypertension, diabetes mellitus, obesity, weight loss, previous coronary artery bypass grafting, previous myocardial infarction, previous coronary artery disease, previous percutaneous coronary intervention, previous cardiac surgery other than coronary artery bypass grafting, previous stroke, atrial fibrillation, previous implantable cardioverter-defibrillator, peripheral vascular disease, anemia, chronic kidney disease, chronic obstructive lung disease, chronic liver disease, coagulopathy and depression, and admission type (elective versus nonelective). Hospital characteristics included location, teaching status, and bed size. Other variables extracted were in-hospital procedures (use of short-term ventricular support) and in-hospital complications. The HCUP Clinical Classification Software and ICD-9-CM codes used to define these variables are listed in Table I in the Data Supplement. Short-term ventricular support was defined as use of either mechanical circulatory support (MCS; Impella/TandemHeart or temporary uni- and biventricular extracorporeal support such as Centrimag), intra-aortic balloon pump, or extracorporeal membrane oxygenation use.

Outcomes

The primary outcome of interest was rate of 30-day all-cause readmissions. Readmissions were identified according to the methodology outlined by HCUP.[9] In brief, patients in the NRD can be tracked using a patient linkage variable, and time to readmission calculated as the number of days between hospital discharge after index admission for LVAD implantation and the first day of hospital readmission using prespecified variables. For patients with multiple readmissions within 30 days, only the first readmission was included for analysis. Transfer to another hospital was not considered as a readmission. The primary diagnosis of each readmission record was identified and grouped into clinically meaningful categories to determine the primary cause of readmission. Causes of readmissions were broadly grouped as cardiac and noncardiac. Primary diagnosis categories and the corresponding Clinical Classification Software and ICD-9-CM codes are listed in Table II in the Data Supplement. Secondary outcomes of interest were length of stay and readmissions total hospital costs. Cost of the primary hospitalization and of readmissions for each individual patient was calculated using standard procedures as outlined by HCUP. In brief, the NRD contains data on total charges for each discharge identified by a total charge variable which represents the amount that hospitals billed for services. These hospital total charge data can be converted to cost estimates by multiplying total charges with the appropriate hospital-specific cost-to-charge ratio. We adjusted hospitalization costs for inflation using the US Bureau of Labor Statistics Consumer Price Index, with the year 2017 as the index base.[10]

Statistical Analysis

Categorical variables are expressed as frequencies and continuous variables as mean±SD or median (interquartile range) as appropriate. Pearson χ^2 test (categorical variables) and Student *t* test (continuous variables) were used to compare baseline patient and hospital characteristics, in-hospital procedures, and in-hospital complications between patients with and without a 30-day readmission. Cox proportional hazards regression analysis was used to identify independent predictors of 30-day readmission. Variables with a $P<0.5$ on univariate analysis were included into a multivariable regression model to identify independent predictors of 30-day readmission. A random-effect term for hospital was also added to the model. Hazard ratios (HRs) and 95% confidence intervals (CIs) are used to report results of Cox regression analyses. Statistical analysis was performed with IBM SPSS Statistics 23.0 (IBM Corp, Armonk, NY). All P values were 2 sided with a significance threshold of 0.05.

RESULTS

Baseline Characteristics

Baseline patient demographics, hospital characteristics, and in-hospital outcomes of LVAD patients who survived their index hospitalization are shown in Table 1. Mean age of the study cohort was 56.3±13.2 years, and 78.5% patients were male. A large majority of LVAD implants were performed in large, urban, teaching hospitals (88.1%). In univariate analysis, compared with patients who were not readmitted within 30 days, those readmitted were more likely to be female, insured by Medicare, treated in a medium-sized hospital, discharged to skilled nursing facility/home with health care, and have a longer length of index hospitalization (defined as ≥31 days; Table 1). No statistically significant differences were noted in patient age, cause of cardiomyopathy (ischemic versus nonischemic), burden of comorbidities (≥4 Elixhauser comorbidities), or disease severity (high All Patients Refined Diagnosis Related Groups severity of illness) between those who were readmitted and those who were not.

Incidence and Predictors of 30-Day Readmission

Among the 2510 patients who survived their index hospitalization, 778 (31.0%) were readmitted within 30 days. The distribution of time to first readmission post-discharge among patients can be seen in Figure 1. Median time to readmission was 10 days (interquartile range, 4–18 days). A total of 677 patients had a single readmission, and 101 patients had >1 readmission within 30 days. Mean length of stay for readmissions was 10.7 days (median, 6 days). On multivariate analysis among those who survived to discharge, female sex (HR, 1.19; 95% CI, 1.01–1.42) and length of index hospitalization ≥31 days (HR, 1.26; 95% CI, 1.07–1.50) were independently associated with higher risk of 30-day readmission, whereas pre-LVAD use of

Table 1. Baseline Characteristics of LVAD Patients Discharged Alive After Index Hospitalization

	Overall (n=2510)	30-Day Readmission Yes (n=778)	30-Day Readmission No (n=1732)	*P* Value
Age, y (mean±SD)	56.3±13.2	56.7±12.5	56.1±13.5	0.25
Age ≥ 55 y	60.0%	62.7%	58.8%	0.07
Men, %	78.5	75.6	79.2	0.02
Primary expected payer, %				0.02
Medicare	47.4	52.4	46.1	
Medicaid	10.3	10.8	10.3	
Private	35.9	32.6	38.0	
Median household income percentile, %				0.64
0–25th	25.6	26.5	25.2	
26–50th	25.3	26.1	24.9	
51–75th	24.8	24.5	24.9	
76–100th	24.4	22.9	25.1	
Comorbidities				
ICM, %	49.0	49.2	49.0	0.90
History of ICD, %	33.8	31.1	35.0	0.06
STEMI at admission, %	3.6	3.2	3.8	0.50
Cardiogenic shock, %	52.8	55.5	51.6	0.07
Short-term support, %				0.02
MCS	2.2	1.4	2.6	
IABP	24.0	27.5	22.5	
ECMO	4.3	3.7	4.6	
Diabetes mellitus, %	33.9	32.5	34.5	0.34
Hypertension, %	45.0	42.0	46.3	0.05
Dyslipidemia, %	36.8	36.6	36.8	0.92
Smoker, %	18.6	19.3	18.3	0.56
Weight loss, %	27.5	26.3	27.9	0.41
Coagulopathy, %	33.7	32.5	34.3	0.38
Depression, %	11.6	12.0	11.5	0.74
COPD, %	12.2	12.6	12.0	0.68
PVD, %	8.5	9.4	8.1	0.30
Known CAD, %	39.9	39.6	40.0	0.84
Previous MI, %	15.7	16.1	15.5	0.73
Previous PCI, %	10.1	10.2	10.0	0.93
Previous CABG, %	8.4	8.4	8.4	0.95
Previous cardiac surgery, %	2.1	1.9	2.1	0.74
Obese, %	17.9	16.1	18.8	0.10
Morbid obesity, %	5.4	6.1	5.0	0.27
Anemia, %	21.9	20.6	22.5	0.27
AF, %	44.3	42.4	45.2	0.19
CKD, %	45.7	47.0	45.2	0.38
CLD, %	3.5	3.1	3.8	0.40

(*Continued*)

Table 1. Continued

	Overall (n=2510)	30-Day Readmission Yes (n=778)	30-Day Readmission No (n=1732)	*P* Value
Previous stroke, %	5.3	4.9	5.5	0.53
Mean number of comorbidities	3.7±2.0	3.7±2.0	3.7±2.0	0.70
>4 Elixhauser comorbidities, %	33.6	33.9	33.5	0.83
Nonelective admission, %	67.9	70.9	66.9	0.05
High risk of mortality*, %	52.5	54.2	51.7	0.23
High severity of illness*, %	93.3	93.2	93.4	0.87
Hospital characteristics				
Hospital bed size, %				0.01
Small	1.9	1.2	2.2	
Medium	8.3	10.9	7.2	
Large	89.8	87.9	90.6	
Urban hospital, %	81.7	86.1	79.7	<0.001
Teaching hospital, %	98.3	98.7	98.1	0.27
In-hospital outcomes				
Discharge disposition, %				0.01
Home (self-care)	33.7	32.4	34.2	
Short-term hospital	2.9	1.3	3.7	
Skilled nursing facility	10.0	11.8	9.2	
Home health care	53.4	54.5	52.9	
Postoperative respiratory failure	1.6	1.9	1.4	0.37
AKI requiring HD	3.6	3.9	3.5	0.68
LOS, d (median, IQR)	31 (21–46)	33 (22–50)	30 (20–44)	0.01
LOS >31 d, %	48.2	53.0	46.1	0.01

AF indicates atrial fibrillation; AKI, acute kidney injury; CABG, coronary artery bypass graft; CAD, coronary artery disease; CKD, chronic kidney disease; CLD, chronic liver disease; COPD, chronic obstructive pulmonary disease; ECMO, extracorporeal membrane oxygenation; HD, hemodialysis; IABP, intra-aortic balloon pump; ICD, implantable cardioverter-defibrillator; ICM, ischemic cardiomyopathy; IQR, interquartile range; LOS, length of stay; LVAD, left ventricular assist device; MCS, mechanical circulatory support; MI, myocardial infarction; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; and STEMI, ST-segment–elevation myocardial infarction.

*Based on APR-DRG coding (All Patient Refined Diagnosis Related Groups).

short-term MCS (HR, 0.53; 95% CI, 0.29–0.98), private insurance (HR, 0.83; 95% CI, 0.70–0.99), and discharge to a short-term hospital facility (HR, 0.41; CI, 0.21–0.78) were independently associated with a lower risk of 30-day readmission (Table 2). To study the additive effect of the above-identified predictors, we devised a score by assigning 1 point each for female sex, length of index hospitalization ≥31 days, nonprivate insurance, no use of MCS before LVAD and discharge destination other than short-term hospital. A statistically significant association was found between

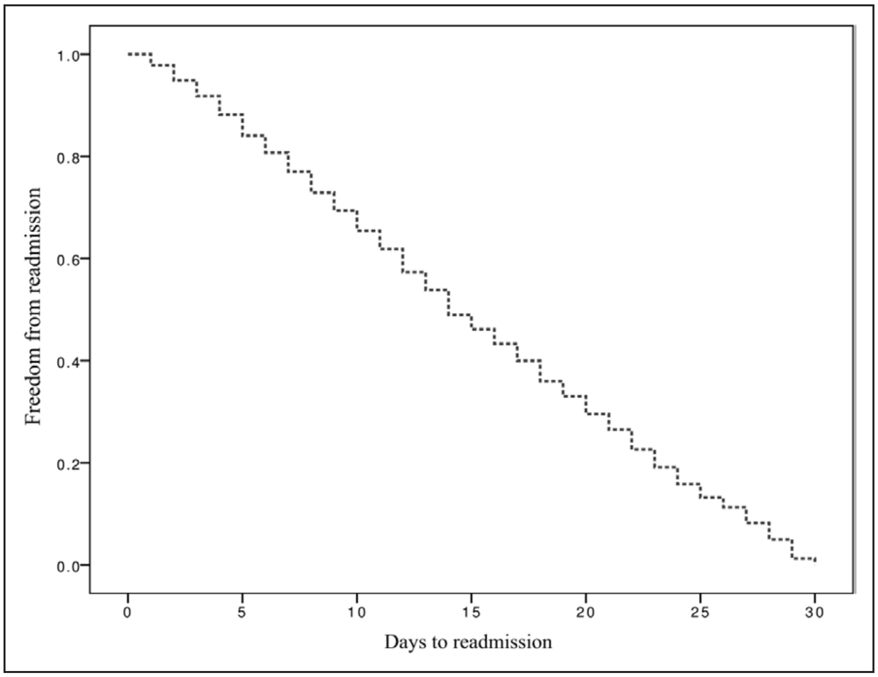

Figure 1. **Kaplan–Meier curve depicting the risk of 30-day readmission among left ventricular assist device recipients.**

a higher score and likelihood of 30-day readmission (*P* trend <0.01; Table 3).

Cause and Cost of 30-Day Readmissions

Causes of 30-day readmission are shown in Figure 2. Among all readmissions, 23.8% were because of cardiac causes. HF was the most common cardiac cause of readmission (13.4% of all), followed by arrhythmias (8.1% of all; Figure 3). Noncardiovascular causes accounted for 76.2% of readmissions. Of these, infectious causes were the most frequent (30.2% overall, with 3.7% being device related and 3.3% secondary to septicemia). Bleeding amounted to 17.6% of total readmissions, of which the largest proportion was identified to be gastrointestinal in origin (15.7% of all). Device-related and surgical complications were noted as primary causes of readmission in 8.2% and 1.7% patients, respectively. Neurological causes (acute cerebrovascular accident 3.3%) resulted in 4.1% of readmissions. Lastly, In-hospital mortality for the first 30-day readmission was 3.3%.

The total aggregate charges attributed to all readmissions within 30 days were $27.18 million. Average hospital cost per readmission was $34 948±2457. Cost of the first 30-day readmission accounted for 4.5% of total cost of episode of care (index+first 30-day readmission).

DISCUSSION

Thirty-day readmissions for cardiac conditions such as HF are publicly reported measures of performance quality.[11] Readmissions not only affect quality of life and cause significant morbidity but also add significantly to healthcare costs. Curtailing them has become a major focus of improved healthcare delivery, and financial penalties have been introduced for rehospitalizations.[12] In this study, using a contemporary nationally representative database, we have demonstrated that 31% of patients who underwent implantation of an LVAD were readmitted within 30 days of discharge with a median time to first readmission of 14 days. Most 30-day readmissions were for noncardiac causes (infections and bleeding being the most frequent), whereas cardiac causes accounted for less than one fourth of all 30-day readmissions. Female sex, nonprivate insurance, a discharge destination other than short-term hospital, and prolonged length of stay (≥31 days) during index hospitalization were independent predictors of 30-day readmission.

We observed that roughly a third of ≈2500 patients were readmitted within 30 days after LVAD implantation. Our results are comparable to those reported in previous smaller studies. Tsiouris et al[13] reported a 30-day readmission rate of 26.1% in 150 patients, whereas the 30-day readmission rate was 35% in a second study of 71 patients.[14] Further, 4.4% patients in our study experienced >1 rehospitalization within 30 days of LVAD implantation, highlighting the high burden of early readmissions in this population. LVAD patients might spend an average of 29.8 days in the hospital during the 2 years after implantation, and such repeated hospitalizations are therefore likely to hinder quality of life.[15] However, despite higher admission rates after LVAD implantation in the recent ROADMAP study, health-related quality of life improved from

Table 2. Predictors of 30-Day Readmission After LVAD

	Univariate HR (95% CI)	Multivariate HR (95% CI)
Women	1.2 (1.02–1.41); *P*=0.027	1.19 (1.01–1.42); *P*=0.046
Private insurance	0.80 (0.69–0.94); *P*=0.006	0.83 (0.70–0.99); *P*=0.03
LOS>31 d	1.26 (1.10–1.45); *P*=0.01	1.26 (1.07–1.50); *P*=0.01
Discharge disposition		0.41 (0.21–0.78); *P*=0.01
Short-term hospital	0.39 (0.21–0.72); *P*=0.003	
Skilled nursing facility	1.28 (1.03–1.59); *P*=0.027	
Short-term support		0.53 (0.29–0.98); *P*=0.04
MCS	0.59 (0.32–1.07); *P*=0.08	
IABP	1.21 (1.03–1.42); *P*=0.02	
ECMO	0.87 (0.60–1.26); *P*=0.46	
Hypertension	0.87(0.75–1.0); *P*=0.048	
Hospital bed size*		
Medium	2.43 (1.22–4.82); *P*=0.01	
Large	1.69 (0.88–3.26); *P*=0.12	
Elective admission	0.86 (0.74–1.0); *P*=0.05	
Age	1.0 (0.99–1.0); *P*=0.25	
Ischemic cardiomyopathy	1.0 (0.87–1.15); *P*=0.97	
STEMI at admission	0.86 (0.57–1.27); *P*=0.44	
Cardiogenic shock	1.13 (0.98–1.30); *P*=0.09	
Diabetes mellitus	0.94 (0.81–1.09); *P*=0.43	
Smoker	1.08 (0.91–1.29); *P*=0.39	
Weight loss	0.95 (0.81–1.11); *P*=0.49	
Coagulopathy	0.92 (0.79–1.07); *P*=0.29	
COPD	1.03 (0.83–1.27); *P*=0.82	
PVD	1.15 (0.91–1.47); *P*=0.24	
History of CABG	1.01 (0.78–1.29); *P*=0.99	
History of other cardiac surgery	0.88 (0.53–1.47); *P*=0.63	
Obese	0.86 (0.72–1.05); *P*=0.13	
Anemia	0.9 (0.76–1.07); *P*=0.23	
AF	0.92 (0.80–1.06); *P*=0.23	
CKD	1.06 (0.92–1.22); *P*=0.41	
CLD	0.82 (0.55–1.24); *P*=0.35	
>4 Elixhauser comorbidities	1.01 (0.88–1.18); *P*=0.85	
Median household income	0.96 (0.90–1.02); *P*=0.21	
Teaching hospital	1.41 (0.76–2.63); *P*=0.28	
High risk of mortality†	1.08 (0.94–1.25); *P*=0.27	
High risk of illness†	1.01 (0.74–1.29); *P*=0.98	

AF indicates atrial fibrillation; CABG, coronary artery bypass graft; CKD, chronic kidney disease; CLD, chronic liver disease; COPD, chronic obstructive pulmonary disease; ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; LOS, length of stay; LVAD, left ventricular assist device; MCS, mechanical circulatory support; PVD, peripheral vascular disease; and STEMI, ST-segment–elevation myocardial infarction.

*Compared with small bed size.

†Based on APR-DRG coding (All Patient Refined Diagnosis Related Groups).

Table 3. Additive Effect of Presence of Predictors on Rates of 30-Day Readmission in LVAD Recipients

No. of Predictors Present	% of all LVAD Patients	% of Patients Readmitted
0	0	…
1	0.5	…
2	17.9	23.6
3	43.7	29.1
4	30.9	35.1
5	6.9	44.3

LVAD indicates left ventricular assist device.

baseline more significantly with LVAD than medical therapy alone.[16]

Infections and bleeding were the leading causes of early readmission in our study, as in previous studies.[17,18] These causes of readmission are distinct from those for other HF populations. Infections after a major surgery, cardiac or otherwise, lead to a large proportion of early readmissions. However, driveline exit site infection and sepsis can be particularly ominous events in the natural history of LVAD patients. Further, LVAD recipients, particularly destination therapy patients, may also be prone to non-LVAD–related infections, and the risk is reported to increase with follow-up.[16] Intensive patient and caregiver education, and meticulous surgical technique are essential to reduce such events. In our study, 17.6% readmissions were secondary to bleeding events, with the majority being gastrointestinal in origin. Therapeutic anticoagulation, an acquired von Willebrand syndrome, as well as formation of arteriovenous, and angiodysplastic malformations in the gastrointestinal tract after implantation of continuous-flow LVADs are implicated.[19,20] The management of anticoagulation in these patients needs to address competing risks of bleeding and pump thrombosis and cardioembolic events. A study from the Mayo Clinic demonstrated that thrombotic events were common after anticoagulation was stopped for bleeding in LVAD patients.[15] Cerebral thrombotic events are most common within the first 30 days after implantation[21] and these accounted a small (3.3%) yet sizable proportion of readmissions in our study.

A little less than one fourth of readmissions in our study were because of a cardiac cause, and only 13.4% of all were HF related. In contrast, as many as 30% to 45% of readmissions in advanced HF patients are secondary to HF exacerbations, confirming the positive impact of LVAD therapy in HF-related morbidity in advanced HF patients.[22] Our findings are analogous to those of a previous study where cardiac causes such as HF and arrhythmias were frequent cardiac causes of readmission in LVAD patients.[15] The second most frequent cardiac cause for readmission in our study was arrhythmias (8.1%) of which 73% were related to ven-

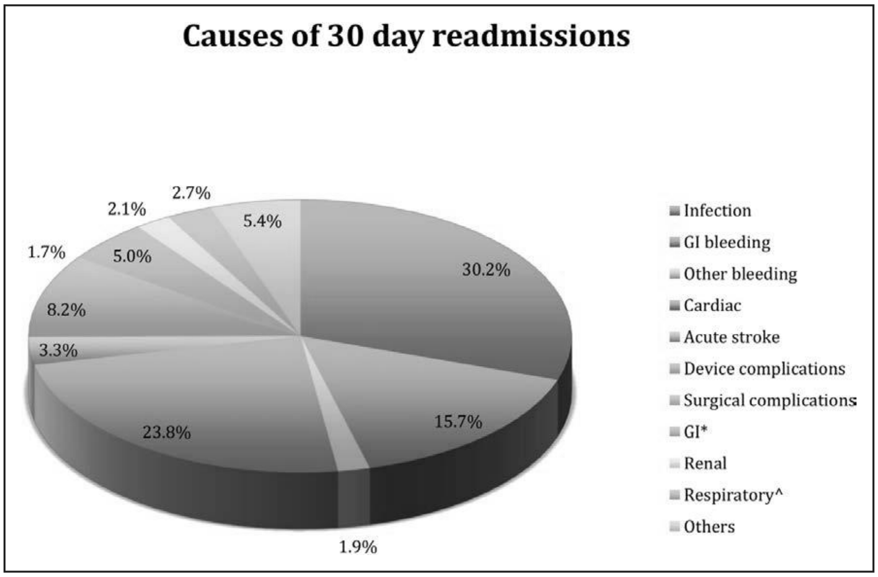

Figure 2. **Causes of 30-day readmission after left ventricular assist device implantation.** *Excludes gastrointestinal (GI) bleeding. ^Excludes infections.

tricular arrhythmias (VA). The incidence of VA is especially high in the early postoperative period, and those with pre-LVAD VA are most at risk for such events.[23] However, despite frequent VA-related admissions, only 1 patient had a cardiac arrest event. This confirms the ability of LVAD patients to tolerate most VA without significant hemodynamic compromise.

Several predictors of high readmission risk emerged on our analysis. Readmission risk was higher in patients with very prolonged index hospitalization. This association has been reported in LVAD patients previously[24] as well as after myocardial infarction[25] and coronary artery bypass grafting[26]; and likely reflects the frailty, high comorbidity burden, and complicated hospital course of this group of patients. Findings of our study also indicate that discharge to a short-term hospital reduced acute readmission compared with other destinations (home/home with health care/skilled nursing facility). Such a strategy should provide an opportunity to better address ongoing issues at the time of initial hospital discharge, allow a smoother transition to care at home, and reduce acute rehospitalizations. We found a lower risk of readmissions among patients with private party insurance compared with Medicare or Medicaid. Medicaid insurance, but not a low socioeconomic status, was associated with poorer outcomes in a study of bridge to transplant VAD patients.[27] We hypothesize that patients with private insurance would have better access to postdischarge care, including physician, and ancillary services such as rehabilitation, psychiatric, and social services leading to better outpatient management of LVAD-related and other issues. Female sex predicted a higher risk of readmission in our study. Many studies have reported more frequent readmissions in

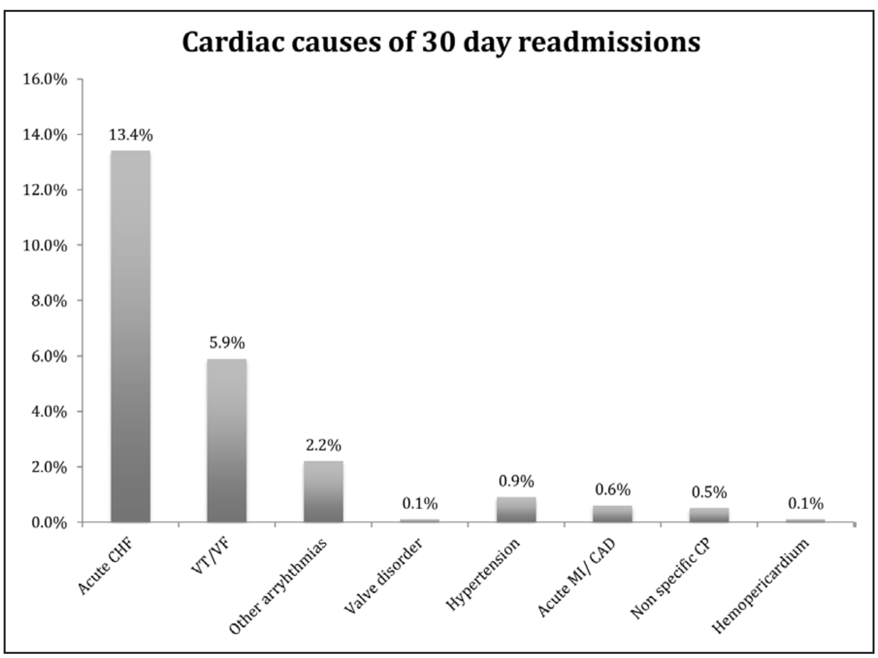

Figure 3. **Cardiac causes of 30-day readmission after left ventricular assist device implantation.** CAD indicates coronary artery disease; CHF, congestive heart failure; CP, chest pain; MI, myocardial infarction; and VT/VF, ventricular tachycardia/ventricular fibrillation.

women with HF and after cardiac surgery,[26,28] whereas others have suggested no sex-based differences.[29] In LVAD patients specifically, the higher rates of readmission in women could be related to disparities in care and their increased risks of infection and bleeding.

Our findings showed that short-term MCS before LVAD implantation independently predicted lower hospital readmission at 30 days among LVAD recipients. Short-term MCS devices are increasingly being used to bridge to more durable support such as an LVAD,[30,31] with a recent systematic review suggesting their use in up to 30% patients before LVAD implantation.[32] Although our findings seem to suggest that pre-LVAD short-term MCS may improve readmission rates in LVAD recipients, it is certainly possible that this finding may represent a survival bias with the sickest patients, and therefore those most at risk of readmission experiencing morality before LVAD implantation or not surviving to discharge after LAVD implantation.

A cost-effectiveness analysis has shown that the costs of cumulative readmissions after LVAD implantation are higher than the cost of either outpatient care or device implantation. Also, mean cost of readmission was reported to be lower before LVAD than after ($19645 versus $12377). Average cost of readmission in our study was ≈$35000 and accounted for 4.5% of total cost of episode of care. Even though LVADs may not be cost-effective, there are currently few other effective treatments for the 500000 patients with advanced HF.[33] Information on causes and predictors of readmission will help care teams and health delivery systems devise strategies to improve cost-effectiveness by reducing readmissions.

Our study has several limitations, some of which are secondary to the administrative nature of our database, its reliance on ICD-9-CM/Clinical Classification Software codes and absence of clinical and laboratory data. Detailed information on underlying cardiomyopathy, indications for LVAD implantation, HF class, severity of shock, concurrent medication use, and incidence of right ventricular failure is either limited or missing. Causes of readmission were identified using the primary discharge diagnosis codes. Patients who are readmitted to a hospital in a different state are not tracked in the NRD. The database is also inadequate in tracking mortality data on patients who died outside of a hospital or in the emergency department.

In conclusion, 30-day readmissions are frequent after LVAD implantation even in contemporary times. In contrast to other HF patients, most admissions in LVAD patients are for noncardiac indications, majority being infection and bleeding related. Longer initial hospital stay, female sex, and nonprivate insurance predicted a higher risk of early readmissions. Costs associated with such readmissions were high and can be expected to have a significant impact on the total cost of healthcare costs in this population. Preimplant evaluation of cognitive function and social support, ongoing patient education and caregiver involvement, and a protocol-driven follow-up using a multidisciplinary approach will be needed to reduce readmissions and improve long-term outcomes in this high-risk population.

DISCLOSURES

None.

AFFILIATIONS

From the Division of Cardiology, St. Luke's University Health Network, Bethlehem, PA (S.A.); Division of Cardiology, Lehigh Valley Health Network, Allentown, PA (L.G., M.S., B.P.); Department of Internal Medicine, University of Tennessee Health Science Center, Memphis (M.A.); Division of Non-Invasive Cardiology, Brigham and Women's Hospital and Harvard Medical School, Boston, MA (A.S.); Division of Cardiology, Newark Beth Israel Medical Center, NJ (A.G.); Division of Cardiology, Montefiore-Einstein Heart Center, Bronx, NY (U.P.J.); and The CardioVascular Center, Tufts Medical Center, Boston, MA (N.K.K.).

FOOTNOTES

Received October 2, 2017; accepted February 1, 2018.

Guest Editor for this paper was Frank W. Sellke, MD.

The Data Supplement is available at http://circheartfailure.ahajournals.org/lookup/suppl/doi:10.1161/CIRCHEARTFAILURE.117.004628/-/DC1.

Circ Heart Fail is available at http://circheartfailure.ahajournals.org.

REFERENCES

1. Starling RC, Naka Y, Boyle AJ, Gonzalez-Stawinski G, John R, Jorde U, Russell SD, Conte JV, Aaronson KD, McGee EC Jr, Cotts WG, DeNofrio D, Pham DT, Farrar DJ, Pagani FD. Results of the post-U.S. Food and Drug Administration-approval study with a continuous flow left ventricular assist device as a bridge to heart transplantation: a prospective study using the INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support). *J Am Coll Cardiol*. 2011;57:1890–1898. doi: 10.1016/j.jacc.2010.10.062.
2. Kirklin JK, Naftel DC, Pagani FD, Kormos RL, Stevenson LW, Blume ED, Miller MA, Baldwin JT, Young JB. Sixth INTERMACS annual report: a 10,000-patient database. *J Heart Lung Transplant*. 2014;33:555–564. doi: 10.1016/j.healun.2014.04.010.
3. Bergethon KE, Ju C, DeVore AD, Hardy NC, Fonarow GC, Yancy CW, Heidenreich PA, Bhatt DL, Peterson ED, Hernandez AF. Trends in 30-day readmission rates for patients hospitalized with heart failure: findings from the get with the guidelines-heart failure registry. *Circ Heart Fail*. 2016;9:e002594. doi: 10.1161/CIRCHEARTFAILURE.115.002594.
4. Cooper LB, DeVore AD, Michael Felker G. The impact of worsening heart failure in the United States. *Heart Fail Clin*. 2015;11:603–614. doi: 10.1016/j.hfc.2015.07.004.
5. Feldman D, Pamboukian SV, Teuteberg JJ, Birks E, Lietz K, Moore SA, Morgan JA, Arabia F, Bauman ME, Buchholz HW, Deng M, Dickstein ML, El-Banayosy A, Elliot T, Goldstein DJ, Grady KL, Jones K, Hryniewicz K, John R, Kaan A, Kusne S, Loebe M, Massicotte MP, Moazami N, Mohacsi P, Mooney M, Nelson T, Pagani F, Perry W, Potapov EV, Eduardo Rame J, Russell SD, Sorensen EN, Sun B, Strueber M, Mangi AA, Petty MG, Rogers J; International Society for Heart and Lung Transplantation. The 2013

International Society for Heart and Lung Transplantation Guidelines for mechanical circulatory support: executive summary. *J Heart Lung Transplant*. 2013;32:157–187. doi: 10.1016/j.healun.2012.09.013.
6. Sajgalik P, Grupper A, Edwards BS, Kushwaha SS, Stulak JM, Joyce DL, Joyce LD, Daly RC, Kara T, Schirger JA. Current status of left ventricular assist device therapy. *Mayo Clin Proc*. 2016;91:927–940. doi: 10.1016/j.mayocp.2016.05.002.
7. Hernandez RE, Singh SK, Hoang DT, Ali SW, Elayda MA, Mallidi HR, Frazier OH, Meyers DE. Present-day hospital readmissions after left ventricular assist device implantation: a large single-center study. *Tex Heart Inst J*. 2015;42:419–429. doi: 10.14503/THIJ-14-4971.
8. Da Silva M, MacIver J, Rodger M, Jaffer M, Raju S, Billia F, Rao V. Readmissions following implantation of a continuous-flow left ventricular assist device. *J Card Surg*. 2016;31:361–364. doi: 10.1111/jocs.12744.
9. US Agency for Healthcare Research and Quality. Overview of Key Readmission Measures and Methods. 2012. http://www.hcup-us.ahrq.gov/reports/methods/methods.jsp. Accessed May 30, 2017.
10. US Bureau of Labor Statistics, Division of Consumer Prices and Price Indexes. Consumer Price Index - All Urban Consumers. 2017. http://data.bls.gov/pdq/SurveyOutputServlet. Accessed May 30, 2017.
11. Medicare.gov. 30-day Unplanned Readmission and Death Measures. 2016. https://www.medicare.gov/hospitalcompare/Data/30-day-measures.html. Accessed May 30, 2017.
12. Burke RE, Coleman EA. Interventions to decrease hospital readmissions: keys for cost-effectiveness. *JAMA Intern Med*. 2013;173:695–698. doi: 10.1001/jamainternmed.2013.171.
13. Tsiouris A, Paone G, Nemeh HW, Brewer RJ, Morgan JA. Factors determining post-operative readmissions after left ventricular assist device implantation. *J Heart Lung Transplant*. 2014;33:1041–1047. doi: 10.1016/j.healun.2014.05.009.
14. Forest SJ, Bello R, Friedmann P, Casazza D, Nucci C, Shin JJ, D'Alessandro D, Stevens G, Goldstein DJ. Readmissions after ventricular assist device: etiologies, patterns, and days out of hospital. *Ann Thorac Surg*. 2013;95:1276–1281. doi: 10.1016/j.athoracsur.2012.12.039.
15. Hasin T, Marmor Y, Kremers W, Topilsky Y, Severson CJ, Schirger JA, Boilson BA, Clavell AL, Rodeheffer RJ, Frantz RP, Edwards BS, Pereira NL, Stulak JM, Joyce L, Daly R, Park SJ, Kushwaha SS. Readmissions after implantation of axial flow left ventricular assist device. *J Am Coll Cardiol*. 2013;61:153–163. doi: 10.1016/j.jacc.2012.09.041.
16. Estep JD, Starling RC, Horstmanshof DA, Milano CA, Selzman CH, Shah KB, Loebe M, Moazami N, Long JW, Stehlik J, Kasirajan V, Haas DC, O'Connell JB, Boyle AJ, Farrar DJ, Rogers JG; ROADMAP Study Investigators. Risk Assessment and comparative effectiveness of left ventricular assist device and medical management in ambulatory heart failure patients: results from the ROADMAP Study. *J Am Coll Cardiol*. 2015;66:1747–1761. doi: 10.1016/j.jacc.2015.07.075.
17. Smedira NG, Hoercher KJ, Lima B, Mountis MM, Starling RC, Thuita L, Schmuhl DM, Blackstone EH. Unplanned hospital readmissions after HeartMate II implantation: frequency, risk factors, and impact on resource use and survival. *JACC Heart Fail*. 2013;1:31–39. doi: 10.1016/j.jchf.2012.11.001.
18. Raju S, MacIver J, Foroutan F, Alba C, Billia F, Rao V. Long-term use of left ventricular assist devices: a report on clinical outcomes. *Can J Surg*. 2017;60:236–246. doi: 10.1503/cjs.010016.
19. Crow S, Chen D, Milano C, Thomas W, Joyce L, Piacentino V III, Sharma R, Wu J, Arepally G, Bowles D, Rogers J, Villamizar-Ortiz N. Acquired von Willebrand syndrome in continuous-flow ventricular assist device recipients. *Ann Thorac Surg*. 2010;90:1263–1269; discussion 1269. doi: 10.1016/j.athoracsur.2010.04.099.
20. Demirozu ZT, Radovancevic R, Hochman LF, Gregoric ID, Letsou GV, Kar B, Bogaev RC, Frazier OH. Arteriovenous malformation and gastrointestinal bleeding in patients with the HeartMate II left ventricular assist device. *J Heart Lung Transplant*. 2011;30:849–853. doi: 10.1016/j.healun.2011.03.008.
21. Pagani FD, Miller LW, Russell SD, Aaronson KD, John R, Boyle AJ, Conte JV, Bogaev RC, MacGillivray TE, Naka Y, Mancini D, Massey HT, Chen L, Klodell CT, Aranda JM, Moazami N, Ewald GA, Farrar DJ, Frazier OH; HeartMate II Investigators. Extended mechanical circulatory support with a continuous-flow rotary left ventricular assist device. *J Am Coll Cardiol*. 2009;54:312–321. doi: 10.1016/j.jacc.2009.03.055.
22. O'Connor CM, Miller AB, Blair JE, Konstam MA, Wedge P, Bahit MC, Carson P, Haass M, Hauptman PJ, Metra M, Oren RM, Patten R, Piña I, Roth S, Sackner-Bernstein JD, Traver B, Cook T, Gheorghiade M; Efficacy of Vasopressin Antagonism in heart Failure Outcome Study with Tolvaptan (EVEREST) investigators. Causes of death and rehospitalization in patients hospitalized with worsening heart failure and reduced left ventricular ejection fraction: results from Efficacy of Vasopressin Antagonism in Heart Failure Outcome Study with Tolvaptan (EVEREST) program. *Am Heart J*. 2010;159:841–849.e1. doi: 10.1016/j.ahj.2010.02.023.
23. Agrawal S, Garg L, Nanda S, Sharma A, Bhatia N, Manda Y, Singh A, Fegley M, Shirani J. The role of implantable cardioverter-defibrillators in patients with continuous flow left ventricular assist devices - a meta-analysis. *Int J Cardiol*. 2016;222:379–384. doi: 10.1016/j.ijcard.2016.07.257.
24. Dunlay SM, Haas LR, Herrin J, Schilz SR, Stulak JM, Kushwaha SS, Shah ND. Use of post-acute care services and readmissions after left ventricular assist device implantation in privately insured patients. *J Card Fail*. 2015;21:816–823. doi: 10.1016/j.cardfail.2015.06.012.
25. Dunlay SM, Weston SA, Killian JM, Bell MR, Jaffe AS, Roger VL. Thirty-day rehospitalizations after acute myocardial infarction: a cohort study. *Ann Intern Med*. 2012;157:11–18. doi: 10.7326/0003-4819-157-1-201207030-00004.
26. Hannan EL, Zhong Y, Lahey SJ, Culliford AT, Gold JP, Smith CR, Higgins RS, Jordan D, Wechsler A. 30-day readmissions after coronary artery bypass graft surgery in New York State. *JACC Cardiovasc Interv*. 2011;4:569–576. doi: 10.1016/j.jcin.2011.01.010.
27. Emani S Tumin D, Foraker RE, Hayes D Jr, Smitsh SA. Impact of insurance status on heart transplant wait-list mortality for patients with left ventricular assist devices. *Clin Transplant*. 2017;31:1399–0012.
28. Giamouzis G, Kalogeropoulos A, Georgiopoulou V, Laskar S, Smith AL, Dunbar S, Triposkiadis F, Butler J. Hospitalization epidemic in patients with heart failure: risk factors, risk prediction, knowledge gaps, and future directions. *J Card Fail*. 2011;17:54–75. doi: 10.1016/j.cardfail.2010.08.010.
29. Lee WY, Capra AM, Jensvold NG, Gurwitz JH, Go AS; Epidemiology, Practice, Outcomes, and Cost of Heart Failure (EPOCH) Study. Gender and risk of adverse outcomes in heart failure. *Am J Cardiol*. 2004;94:1147–1152. doi: 10.1016/j.amjcard.2004.07.081.
30. Gaudard P, Mourad M, Eliet J, Zeroual N, Culas G, Rouvière P, Albat B, Colson P. Management and outcome of patients supported with Impella 5.0 for refractory cardiogenic shock. *Crit Care*. 2015;19:363. doi: 10.1186/s13054-015-1073-8.
31. Canver CC. Adoption of short-term mechanical circulatory support as a viable rescue effort for patients with refractory cardiogenic shock. *J Thorac Cardiovasc Surg*. 2017;153:763–764. doi: 10.1016/j.jtcvs.2016.11.025.
32. den Uil CA, Akin S, Jewbali LS, Dos Reis Miranda D, Brugts JJ, Constantinescu AA, Kappetein AP, Caliskan K. Short-term mechanical circulatory support as a bridge to durable left ventricular assist device implantation in refractory cardiogenic shock: a systematic review and meta-analysis. *Eur J Cardiothorac Surg*. 2017;52:14–25. doi: 10.1093/ejcts/ezx088.
33. Baras Shreibati J, Goldhaber-Fiebert JD, Banerjee D, Owens DK, Hlatky MA. Cost-effectiveness of left ventricular assist devices in ambulatory patients with advanced heart failure. *JACC Heart Fail*. 2017;5:110–119. doi: 10.1016/j.jchf.2016.09.008.