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National Landscape of Hospitalizations in Patients with Left Ventricular Assist Device. Insights from the National Readmission Database 2010–2015

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The number of patients with left ventricular assist devices (LVAD) has increased over the years and it is important to identify the etiologies for hospital admission, as well as the costs, length of stay and in-hospital complications in this patient group. Using the National Readmission Database from 2010 to 2015, we identified patients with a history of LVAD placement using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) code V43.21. We aimed to identify the etiologies for hospital admission, patient characteristics, and in-hospital outcomes. We identified a total of 15,996 patients with an LVAD, the mean age was 58 years and 76% were males. The most common cause of hospital readmission after LVAD was heart failure (HF, 13%), followed by gastrointestinal (GI) bleed (11.8%), device complication (11.5%), and ventricular tachycardia/fibrillation (4.2%). The median length of stay was 6 days (3–11 days) and the median hospital costs was $12,723 USD. The in-hospital mortality was 3.9%, blood transfusion was required in 26.8% of patients, 20.5% had acute kidney injury, 2.8% required hemodialysis, and 6.2% of patients underwent heart transplantation. Interestingly, the most common cause of readmission was the same as the diagnosis for the preceding admission. One in every four LVAD patients experiences a readmission within 30 days of a prior admission, most commonly due to HF and GI bleeding. Interventions to reduce HF readmissions, such as speed optimization, may be one means of improving LVAD outcomes and resource utilization.

Key Words: LVAD, ventricular assist device, hospitalizations, resource utilization

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The use of durable left ventricular assist devices (LVAD) for the management of end-stage heart failure (HF) has increased significantly over the past decade. Based on data from the 2019 Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS), over 25,000 patients have received durable mechanical circulatory support in the United States[1] and rates of 30-day (now ~4%) and 1-year mortality (now ~17%) have declined over time.[2] Despite these gains, resource utilization after LVAD implant remains high. Only one in five LVAD patients do not have a readmission within 12 months of LVAD implant, dropping to 7% of patients by 36 months.[3]

Patients on LVAD support are prone to bleeding complications, neurologic events, right HF, infection and device complications.[1] Aside from the incremental morbidity suffered by individuals from these adverse events, readmissions contribute to higher healthcare costs along with a decrease in patient quality of life.[2,4,5] While improved survival is critically important for patients with end-state HF, therapeutic "success" on LVAD support requires consideration of morbidity and readmission burdens. Identification of adverse events with the highest frequency and/or with the highest associated readmission costs can also help the field focus on technological advancements that are imperative for cost effectiveness.

Using a large national database, we aimed to 1) better scrutinize the hospital readmission burden in patients on LVAD support and 2) to characterize the associated costs associated with hospital admissions in these patient population.

Methods

Data Source

The study cohort was derived from the National Readmission Database (NRD), a publicly available database of all-payer hospital inpatient stays developed by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project. The study included the NRD databases from January 2010 to August 2015. The NRD was constructed from 22 states with reliable, verified patient linkage numbers in the State Inpatient Databases that could be used to track the patient across hospitals within a state, while adhering to strict privacy guidelines. The NRD database includes approximately 14 million patients and around 2,000 hospitals per year. National estimates are obtained using sampling weights provided. This study was deemed exempt by the Institutional Review Board as the NRD is a publicly available database that contains de-identified patient information.

Study Cohort

Patients comprising the LVAD cohort of study were identified in the NRD using the International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) diagnostic code V43.21 ("organ or tissue replaced by heart assist device"). This ICD-9 code does not allow one to identify the index admission for LVAD implant; it only identifies patients with a durable LVAD during the period of study. For example, a patient may have been implanted in 2007 or 2009. For the purposes of this analysis, an LVAD admission had to occur between 2010 and 2015 and was defined as the primary admission herein for the readmission analyses. Admissions after the primary admission were tracked as "readmissions." In the NRD, patients are assigned a unique identifier, which allows each LVAD patient to be tracked (the variable named "NRD_visitlink") across admissions. We determined the time between the first admission captured in the NRD and subsequent readmission(s) by using the variable "NRD_daystoevent," calculating the difference between that variable and the length of stay (LOS). A detailed explanation of all the variables in the NRD is available online (https://www.hcup-us.ahrq.gov/nrdoverview.jsp).

All hospital admissions in the NRD containing the V43.21 code for the period of study were included in the analyses. Subsequently, the five most common etiologies for hospital admission were analyzed separately. We considered the primary admission the first hospital stay of the year in patients with the ICD-9 code V43.21; hereafter, any admission within 30 days of discharge following this primary admission was considered the readmission. Supplemental Table 2 (Supplemental Digital Content 1, http://links.lww.com/ASAIO/A482) included the ICD-9 codes used to identify the top 5 etiologies for hospital admission in the LVAD cohort. To verify that the ICD-9-CM diagnostic code V43.21 was reflective of patients on active LVAD support, and not just those who at any time were supported with an LVAD, we studied patients (n = 985) with an LVAD that underwent heart transplantation or LVAD removal. We found that those patients with subsequent admissions after LVAD removal no longer had the V43.21 ICD-9 code assigned. Based on the NRD suggested exclusion criteria,[6] we excluded records of patients younger than 18 years of age (n = 86), those admitted during the month of December (for the years 2011 to 2014, and September for 2015) (n = 1,793), same day admission-transfers (n = 1,292), out of state patients (n = 3,251), and patients who did not have mortality data (n = 15).

Patient and Hospital Characteristics

Baseline patient characteristics such as age, gender, primary expected payer, relevant comorbidities were collected using already defined variables in the NRD database or by using ICD9 codes (see Table 1, Supplemental Digital Content 1, http://links.lww.com/ASAIO/A482). The severity of comorbid conditions was defined using a validated Deyo modification of Charlson Comorbidity Index.[7,8] Other characteristics such as teaching status of the hospital, median household income, insurance status, elective admission status, and discharge disposition were also included.

Study Outcomes

Study outcomes were divided as resource utilization and clinical outcomes. Resource utilization comprised LOS, median hospital costs per patient, total hospital costs, use of echocardiogram (transthoracic or transesophageal), right heart catheterization, mechanical ventilation, repair or replacement of LVAD, palliative care consultation, and blood transfusion. Clinical outcomes included in-hospital mortality, 30-day all-cause readmission (both unplanned and planned readmissions were included), acute kidney injury (AKI), AKI requiring dialysis, heart transplantation, ischemic stroke, hemorrhagic stroke, bleeding, device complication, HF, and discharge to a nursing home or skilled facility. The ICD-9-CM codes used to identify and define these variables are listed in Tables 1 and 2 (Supplemental Digital Content 1, http://links.lww.com/ASAIO/A482).

Results

A total of 15,996 patients on LVAD support were identified as having at least one admission during the period of study. **Table 1** outlines the clinical characteristics and demographics of the cohort. The mean age was 58 years (SD, 13.3), 51.8% of patients were older than 60 years, and only 24% were female. The majority of patients were admitted to large teaching hospitals and 57.9% had Medicare as their primary insurance.

Clinical Outcomes and Resource Utilization of the Entire Readmission Cohort

Between 2010 and 2013, there was a decline in readmission frequency in patients on LVAD support, from 28% to 23% (**Figure 1**). After 2013, readmission rates demonstrated an increase. This trend mirrors the trend in increased LVAD utilization across the United States.

The most common diagnoses for hospital readmission in patients with LVAD implant included acute HF (2,079 [13.0%]), gastrointestinal (GI) bleeding (1,891 [11.8%]), device complications (1,837 patients [11.5%]), ventricular tachycardia (VT) (666 [4.2%]), and acute cerebrovascular disease (530 [3.3%]). The complete list of hospitalization etiologies can be found in Supplemental Table 3 (Supplemental Digital Content 1, http://links.lww.com/ASAIO/A482). At 30 days from the primary admission, the readmission rate was 24.9%. Interestingly, the top reasons for 30-day readmission were the same as the primary admission diagnosis after ventricular assist devices (VAD) stay (**Figure 2**).

The in-hospital mortality at primary admission within the LVAD sample was 3.9%. One in every five patients developed AKI, 6.2% underwent heart transplantation, and 5.4% of patients were discharged to nursing home or skilled nursing facility. The overall median LOS was 6 days (interquartile range [IQR]: 3–11), median hospital costs per patient were $12,723 (**Figure 3**), and the total hospital costs for the entire cohort was $510 million.

Acute Heart Failure

Heart failure was the most common reason for primary hospitalization in the LVAD cohort, affecting 13%. The mean age was 56.5 (SD, 12.7) years old and 25% were female. Compared with the overall LVAD cohort, patients with an admission for heart failure were more often obese (23.4%), with high frequencies of atrial fibrillation, advanced chronic kidney disease (CKD) and/or end stage renal disease (ESRD). The median

Table 1. Baseline Patient and Hospital Characteristics by Primary Admission Diagnosis

	Overall	Acute Heart Failure	Gastrointestinal Bleeding	Device Complication	Ventricular Tachycardia	Acute Cerebrovascular Disease
No. of patients (% of overall population)	15,996 (100%)	2,079 (13.0%)	1,891 (11.8%)	1,837 (11.5%)	666 (4.2%)	530 (3.3%)
Age, mean (SD)	58.0 (13.3)	56.5 (12.7)	63.0 (10.5)	54.7 (14.4)	58.6 (12.8)	58.9 (11.8)
<40 years old	10.4%	11.6%	2.7%	15.4%	8.4%	8.0%
40–49 years old	12.9%	13.0%	7.2%	17.3%	14.1%	11.5%
50–59 years old	24.9%	27.6%	21.4%	26.0%	25.2%	25.4%
60–69 years old	32.2%	35.3%	39.7%	25.3%	29.5%	37.7%
70–79 years old	17.6%	11.5%	26.9%	14.8%	21.5%	16.5%
≥80 years old	2.0%	1.0%	2.2%	1.1%	1.3%	9.7%
Female	24.0%	25.0%	23.8%	27.1%	14.5%	20.4%
Comorbidities						
Hypertension	56.0%	53.9%	63.6%	52.0%	57.8%	64.6%
Dyslipidemia	40.9%	39.3%	47.7%	37.5%	43.4%	44.7%
Diabetes	38.1%	40.0%	40.1%	38.8%	35.8%	37.9%
Diabetes with insulin use	8.9%	8.7%	8.1%	5.2%	10.5%	5.7%
Prior MI	18.8%	16.1%	21.8%	15.4%	22.5%	17.0%
Prior PCI	10.2%	9.4%	9.7%	6.4%	12.3%	12.7%
Previous CABG	14.2%	14.9%	21.9%	8.6%	13.3%	14.1%
Prior pacemaker	2.2%	3.1%	2.9%	1.9%	1.4%	5.1%
Prior ICD	17.5%	15.3%	17.4%	17.3%	30.1%	17.9%
Atrial fibrillation	36.1%	40.3%	41.5%	31.9%	48.6%	38.5%
COPD	14.3%	12.0%	19.9%	11.3%	15.9%	13.7%
Advanced CKD	17.8%	22.7%	21.8%	18.8%	17.3%	16.8%
ESRD	2.0%	2.5%	0.6%	0.3%	2.7%	2.4%
Carotid artery disease	0.8%	0.4%	0.9%	0.3%	0.5%	3.6%
Prior CVA	13.3%	10.3%	12.2%	12.0%	10.1%	14.4%
Peripheral vascular disease	6.9%	6.6%	7.7%	7.9%	5.4%	6.0%
Obese	17.0%	23.4%	11.7%	21.9%	16.9%	11.7%
Anemia	24.6%	31.4%	20.2%	26.6%	20.5%	25.9%
Liver disease	2.2%	2.8%	3.7%	1.6%	0.2%	1.1%
Alcohol abuse	1.7%	2.5%	1.1%	1.7%	0.2%	1.0%
Drug abuse	1.9%	2.2%	1.2%	3.5%	1.7%	1.0%
Coagulopathy	10.7%	16.4%	7.0%	12.7%	3.1%	10.6%
Hypothyroidism	16.7%	18.2%	18.1%	15.9%	14.7%	18.5%
Valve disease	11.4%	0.3%	17.0%	11.5%	0.0%	15.0%
Chronic antiplatelet/ antithrombotic use	21.7%	21.5%	20.8%	18.1%	27.3%	20.0%
Smoking history	28.0%	23.2%	33.2%	26.0%	31.6%	24.3%
Other characteristics						
Hospital bedsize						
Small	1.3%	0.9%	1.0%	0.2%	0.9%	2.5%
Medium	6.4%	6.4%	5.5%	7.5%	4.7%	5.3%
Large	92.3%	92.7%	93.5%	92.3%	94.3%	92.2%
Teaching hospital	95.8%	96.1%	97.3%	97.1%	96.6%	96.1%
Elective admission	19.5%	23.2%	15.3%	15.6%	10.6%	7.6%
Primary payer						
Medicare	57.9%	53.8%	64.5%	57.4%	60.6%	58.4%
Medicaid	10.6%	11.6%	7.0%	15.6%	8.3%	8.1%
Private insurance	28.4%	30.8%	25.3%	24.3%	29.1%	32.7%
Self-pay/other	3.0%	3.8%	3.3%	2.7%	2.0%	0.8%
Median household income						
0–25th percentile	28.7%	30.9%	30.0%	29.8%	29.5%	26.1%
26th–50th percentile	25.0%	25.5%	25.1%	25.7%	20.3%	27.2%
51st–75th percentile	24.1%	23.0%	22.2%	25.5%	26.4%	26.9%
76th–100th percentile	22.2%	20.7%	22.7%	19.0%	23.4%	19.8%
Publication year						
2010	6.8%	8.3%	5.0%	6.6%	7.6%	8.7%
2011	11.0%	13.5%	8.5%	9.4%	9.9%	9.5%
2012	15.0%	14.5%	13.0%	11.6%	13.7%	11.5%
2013	20.1%	19.3%	23.0%	21.2%	22.1%	21.8%
2014	23.7%	22.1%	26.0%	22.5%	25.4%	23.1%
2015*	23.4%	22.3%	24.5%	28.7%	21.3%	25.5%

*From January to September 2015.

CABG, coronary artery bypass graft; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; ESRD, end stage renal disease; ICD, implantable cardioverter-defibrillator; MI, myocardial infarction, PCI, percutaneous coronary intervention.

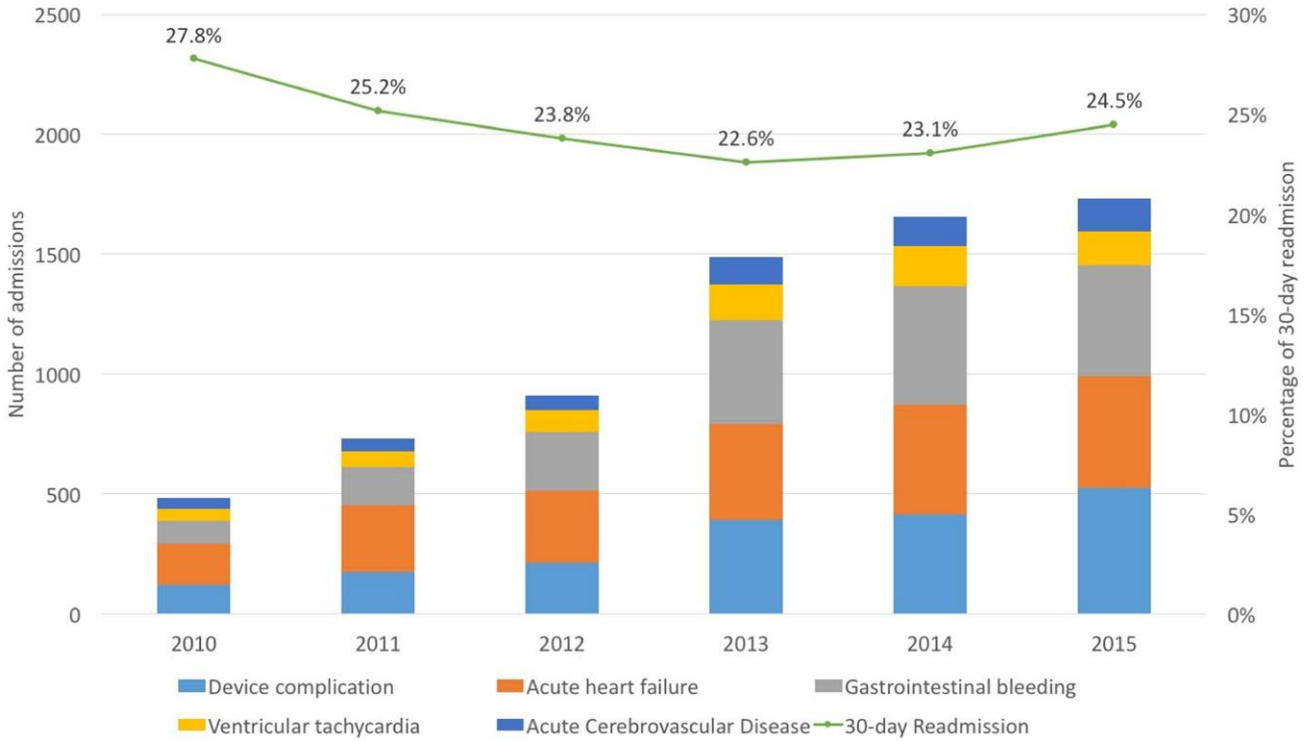

Figure 1. Primary admission diagnosis by year in patients with LVAD. The number of hospitalizations in patients with LVAD has increased from around 500 patients in 2010 to more than 1700 patients in 2015. Between 2010 and 2013, there was a decline in readmission frequency in patients on LVAD support, from 28 to 23%; after 2013, readmission rates demonstrated an increase. full color online

LOS was eight (4–14) days and hospital costs ($15,759) were approximately $3,000 higher than that of the overall cohort. While in-hospital mortality was lower (2.8%) than that of the general LVAD cohort, the rate of heart transplantation was highest at 19.2%. This group also had high requirements for mechanical ventilation (7%) with the highest frequency of AKI (30.8%). Finally, use of echocardiography (13.5%) was higher than that of the general cohort of patients with LVAD and right heart catheterizations (8.3%) occurred with the highest frequency in this group.

Gastrointestinal Bleeding

A total of 1,891 (11.8%) LVAD patients had a primary hospital admission due to GI bleeding in the study period. Patients in this group were older (63 years old) than the general LVAD cohort, and more GI bleed patients had hypertension, chronic obstructive pulmonary disease, atrial fibrillation, prior coronary artery bypass graft or percutaneous coronary intervention, hypothyroidism, advanced CKD, and smoking history. There were fewer patients with obesity and ESRD in those with GI bleeding. The median

Figure 2. Median hospital costs for each hospital admission in the LVAD cohort. full color online

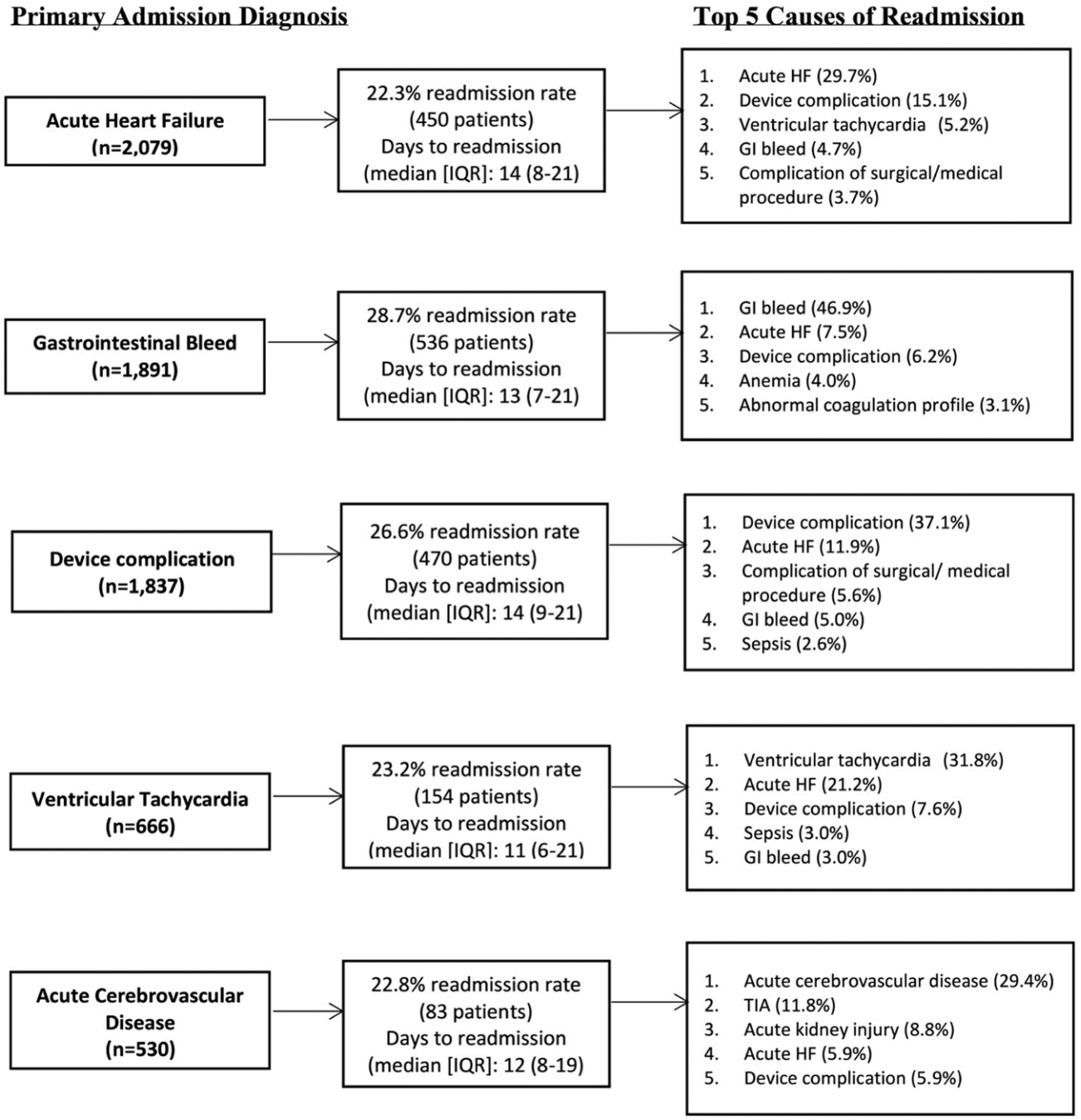

Figure 3. Most common 30-day readmission causes by group. There were 15,996 patients in the total cohort. The first box shows the indications for readmission in order of frequency. The second box shows the readmission rate at 30-day for the given primary readmission diagnosis. The final box breaks down the causes of readmission after first readmission. For example, acute heart failure was the most common cause of primary admission. Of these, 22% were readmitted in 30 days and 29% were readmitted for another acute HF flair.

LOS was similar to the total cohort at 7 days (4–11) and in-hospital mortality was the second lowest (1%) of the complications. However, hospital costs ($14,346) were approximately $1,600 higher than average; 71.4% of patients required a blood transfusion and 67% of patients had upper endoscopy and/or colonoscopy was performed. The 30-day readmission rate after a GI bleed was the highest for any complication at 28.7%, and half of these patients were admitted for a recurrent GI bleed.

Device Complication

A total of 1,837 hospitalizations occurred due to device complications, representing 11.5% of all hospitalizations in patients on an LVAD. Females and young patients were more likely to experience device complications (**Table 1**). Compared to the overall LVAD cohort, the median LOS was longer (8 days [IQR: 4–15]), and complication burdens were high: Almost 25% of patients had sepsis, 7.3% of patient required repair or replacement of the LVAD (compared

with 0.9% of the general VAD readmission cohort), 18.1% of patients required blood transfusions, 25% had AKI, and 2.1% had heart transplant. Compared with other complications, in-hospital mortality in patients admitted with a device dysfunction was second highest at 3.8% and hospital costs ($17,490) were the highest.

Ventricular Tachycardia

Ventricular tachycardia was the admission diagnosis for 4.2% of patients (4.2%). Patients with VT were least likely to be female and more likely to have had prior myocardial infarction and/or revascularization (**Table 1**). An implantable cardioverter-defibrillator (ICD) was present in 30% of patients and 6.8% of patients without a prior ICD underwent ICD placement. Among patients admitted with VT, 8.9% underwent catheter ablation. The LOS (4 days [2–6]), hospital costs ($8,534), and in-hospital mortality (0.5%) were lowest in this cohort.

Acute Cerebrovascular Disease

While acute cerebrovascular disease had affected only 3.3% of the overall cohort (530 patients), the complication was associated with the poor clinical outcomes and high costs. The mean age was 59.9 years and 20.4% were females. More patients had hypertension (64.6%) and carotid artery disease (3.6%) when compared to the overall LVAD cohort. While the mean LOS (6 days [2–12]) approximated that of the general cohort, hospital costs were the second highest of the complications at $16,218, and complications including need for mechanical ventilation (26%), requirement for blood transfusions (23.5%), and development of sepsis (10.4%) were high. Palliative care consultation was overall low in the study (2.5% of the general population) but patients with acute cerebrovascular events triggered their services in 16.6%. Congruently, the in-hospital mortality was the highest among the other cohorts (30.8%), and 10.9% of patients were discharged to a nursing home or skilled nursing facility compared with only 5% of the general cohort.

Discussion

In this large national database study, we attempted to characterize the patient journey during LVAD support, including the burden of readmissions, morbidities, and mortality. In addition, we examined the morbidity impact of the most common causes for readmission and their associated costs. Our findings are congruent with previous studies identifying acute heart failure, bleeding, device complication, and arrhythmias as the most common etiologies for hospital admission post-LVAD.[1,3,5,9–18] What is added to the literature is the finding that subsequent re-admissions are most commonly for the same reason as the primary admission. The complication of highest frequency in patients with LVAD was heart failure, leading to the highest total hospital costs at $99 million. While GI bleeding is a low mortality complication, hospital costs are not trivial and readmission rates are high, making it the third most costly complication for the health system at $41 million. Overall, while LVAD technology has improved with improved survival, our composite results and utilization data suggest the field has a long way to go before we can call LVAD support a true "success."

In this analysis, acute heart failure was the most common indication for admission in patients on LVAD support, consistent with findings in previous studies.[2,5,15,16,19] As a cohort, this group of patients was the most costly in terms of absolute health care dollars spent- accounting for $98.5 million. There was also a drastically elevated rate of transplant in this group, occurring in 19.2% of patients during that hospital admission for heart failure. This is a finding that has not previously been reported and we hypothesize that it reflects the development of new or progressive right heart failure after LVAD implant. This hypothesis is supported by the increased frequency of acute renal injury, use of renal replacement therapy, and right heart catheterization during their hospitalization. The re-admission rate post discharge was 22.3% which was the lowest of the five groups. This is at least in part attributed to the fact that nearly one in five of these patients received a transplant. Despite this, admission for acute heart failure in those surviving to discharge approached 30%.

Gastrointestinal bleeding represented the second most common admission indication in our study which again is similar to prior studies and consistent with reports from INTERMACS.[1,3,15]

What is added is that we found this to be the most common diagnosis resulting in hospital re-admission and the strongest predictor of recurrent GI bleeding. Unsurprisingly this group utilized blood transfusions at a significantly higher rate than the others (71.8% *vs*. 26.8% overall). Interestingly GI bleed was associated with the second fewest comorbid acute conditions during hospitalization but the highest frequency of re-admission (28.7%) with nearly half of those being due to subsequent GI bleed.

Device complication represented the third most common indication for hospital admission following LVAD.[15,16] This is a broad and heterogenous group that in our study included infection, driveline fracture, pump thrombosis, and failure along with many others (**Table 2**). Device complication requiring re-admission occurred in 11.5% of patients. This accounted for 15.9% of total costs, second only to heart failure as primary cause of admission, with the highest per patient cost averaging $17,490/hospitalization. Analysis identified this group as an above average risk for re-admission as well with 26.6% presenting within 30 days for a subsequent admission with recurrent device complication being the primary reason in 37% of patients returning (**Figure 2**). As a group these patients tended to be younger, female, and have non-ischemic causes for their heart failure.

Ventricular tachycardia occurred as the fourth most prevalent readmission diagnosis in this study affecting 4.4% of patients and at an average hospitalization cost significantly lower than all other top 5 diagnosis. Ventricular tachycardia is well described in the post-LVAD population[20,21] and has been attributed to a multitude of factors including those directly related to the pump such as suction events and myocardial scar around the implant site. Additionally, physiologic changes post-VAD have been described as potential etiologies of early ventricular arrhythmias due to rapid shifts in myocardial electrolytes resulting in arrhythmophilic states as well as more whole-body systemic electrolyte imbalances due to sudden improved renal function and kaliuresis.[20] Short term these arrhythmias are well tolerated by most VAD patients due to the

Table 2. Resource Utilization and Hospital Outcomes by Primary Admission Diagnosis

		Primary Admission Diagnosis				
	Overall	Acute Heart Failure	Gastrointestinal Bleeding	Device Complication	Ventricular Tachycardia	Acute Cerebrovascular Disease
Resource utilization						
Length of stay, median (IQR)	6 (3–11)	8 (4–14)	7 (4–11)	8 (4–15)	4 (2–6)	6 (2–12)
Median total hospital costs (million US$)	510.0	98.5	41.2	81.4	13.9	20.0
Echo/TEE	10.2%	13.5%	2.8%	14.7%	12.9%	10.7%
Right heart catheterization	3.1%	8.3%	1.3%	3.1%	1.1%	1.1%
Repair or replacement of VAD	0.9%	0.1%	0.1%	7.3%	0.0%	0.4%
Mechanical ventilation	6.2%	7.0%	0.3%	6.1%	3.0%	26.0%
Sepsis	10.7%	6.5%	3.7%	24.9%	1.6%	10.4%
Palliative care consultation	2.5%	1.7%	1.1%	2.9%	1.5%	16.6%
Blood transfusion	26.8%	9.1%	71.4%	18.1%	9.4%	23.5%
Clinical outcomes						
In-hospital mortality	3.9%	2.8%	1.0%	3.8%	0.5%	30.8%
30-day readmission rate*	24.9%	22.3%	28.7%	26.6%	23.2%	22.8%
Acute kidney injury	20.5%	30.8%	14.8%	25.2%	14.5%	15.7%
AKI requiring dialysis	1.6%	2.7%	0.3%	1.0%	0.8%	1.2%
Heart transplantation	6.2%	19.2%	0.2%	2.1%	0.8%	0.4%
Ischemic stroke	2.9%	0.4%	0.3%	2.8%	0.2%	56.2%
Hemorrhagic stroke	1.3%	0.3%	0.0%	1.2%	0.8%	43.8%
Discharge to nursing home/facility	5.4%	5.0%	4.2%	5.4%	4.5%	10.9%

*Patients that survived primary admission.
AKI, acute kidney injury; IQR, interquartile range.

continuous unloading of the left ventricle, however, over time there is significant detrimental effect to the RV when left unchecked. Our data demonstrates this as 23.2% of patients who presented with VT will have subsequent admission within 30 days with more than 20% of those presenting with acute HF and acute renal injury in nearly 15%. The overall cost burden is low for this group and likely reflects the relative tolerance and hemodynamic stability as the rates of acute comorbidities was lowest in this group and were the least likely to undergo procedural intervention. This is largely attributed to the vast majority of patients receiving LVAD already having intracardiac defibrillators in place.[22] There has been increasing investigations into the practicality and durability of VT ablation both intraoperatively and postoperative for reducing long-term arrhythmia burden.[21,23,24]

Finally, acute cerebrovascular events are the final major readmission diagnosis that this data set identified. Although this occurs in a small group of patients, 3.3% of the study population, it has the most profound effect on morbidity and mortality.[3] Baseline characteristics also demonstrated a significant preexisting cerebrovascular disease burden in this subgroup with 14.4% having prior cerebrovascular accident (CVA) compared to a 12.5% for the remaining four groups. Nearly one in three patients suffered in-hospital mortality and a quarter required mechanical ventilation. The median cost of acute CVA was exceeded only by device complications and is a reflection of the acuity of illness this cohort represents with high intensive care usage and significant comorbid conditions including high rates of AKI, transfusions, and importantly sepsis. Ischemic stroke represented the majority of acute CVA in our study at 56.2% *vs*. 43.8% hemorrhagic. With newer technology and improved device design, rates of complications can potentially be reduced; as seen in MOMENTUM 3 trial, which showed lower rates of stoke among patients with centrifugal-flow pump when compared with axial-flow pumps (10.1% *vs*. 19.2%, $P = 0.02$).[25] There is a preponderance of evidence in the literature demonstrating a high correlation within the LVAD population for cerebrovascular accidents to be preceded by bacteremia or other device related infection.[26–29] Further chronic changes suffered by patients with long-standing heart failure have been shown to cause changes to the blood brain barrier, cerebral autoregulation, and histological changes the central nervous system arterioles.[30–32]

Limitations

There are several limitations to the current study due to the administrative nature of the database. It is not possible to identify the type of durable LVAD implanted and precisely when the operation occurred, limiting our ability to examine outcomes and costs by brand. Further, it is not possible to distinguish some in-hospital complications from comorbidities with this administrative database. This is a critical limitation for stroke outcomes. The mortality data does not distinguish between cardiac and non-cardiac causes of death and this analysis is limited to in-hospital outcomes. The NRD data are based on ICD-9-CM codes and there is a possibility of coding error as well as under coding certain diagnoses. Finally, the lack of information about laboratory results, medications, and diagnostic imaging results is also a limitation. Despite these limitations, by using the largest national sample of hospital admissions in the United States, this study showed important findings among patients with an LVAD and their resource utilization and hospital outcomes.

Conclusion

In conclusion, the overall frequency of admissions in LVAD patients remains elevated and long-term cost burdens continue

to be significant. As the field advances, it will be critical to capture outcomes that extend beyond survival so that a clearer understanding of the patient journey is resulted. A focus on reducing health care dollars through improved technology with low readmission and morbidity burdens should be a priority for the field of mechanical circulatory support.

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