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Readmission and resource utilization after orthotopic heart transplant versus ventricular assist device in the National Readmissions Database, 2010–2014[☆]

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ABSTRACT

Background: As the technology of ventricular assist devices continues to improve, the morbidity and mortality for patients with a ventricular assist device is expected to approach that of orthotopic heart transplantation. The present study was performed to compare perioperative outcomes, readmission, and resource utilization between ventricular assist device implantation and orthotopic heart transplantation, using a national cohort.
Methods: Patients who underwent either orthotopic heart transplantation or ventricular assist device implantation from 2010 to 2014 in the National Readmission Database were selected.
Results: Of the 12,111 patients identified during the study period, 5,440 (45%) received orthotopic heart transplantation, while 6,671 (55%) received ventricular assist devices. Readmissions occurred frequently after ventricular assist device implantation and orthotopic heart transplantation, with greater rates at 30 days (29% versus 24%, $P=.005$) and 6 months (62% versus 46%, $P < .001$) for the ventricular assist device cohort. Cost of readmission was greater among ventricular assist device patients at 30 days ($29,115 versus $21,586, $P=.0002$) and 6 months ($34,878 versus $20,144, $P=.0106$).
Conclusion: Readmission rates and costs for patients with a ventricular assist device remain greater than their orthotopic heart transplantation counterparts. Given the projected increases in ventricular assist device utilization and limited transplant donor pool, further emphasis on cost containment and decreased readmissions for patients undergoing a ventricular assist device is essential to the viability of such therapy in the era of value-based health care delivery.

Introduction

Nearly 6.5 million Americans live with heart failure (HF), a condition accounting for an estimated $35 billion of annual health care expenditure in the United States.[1] Mortality after inpatient admission for HF has been estimated to be as great as 35% within 1 year and 75% within 5 years.[2] HF leads federal funding mandates, and a disproportionate amount of resources are aimed at the management of advanced HF. With the combination of an aging population and increasing burden of ischemic heart disease, the prevalence of end-stage HF continues to rise.[3,4]

Although orthotopic heart transplantation (OHT) is widely accepted as the gold standard therapy for end-stage HF, ventricular assist devices (VADs) have improved outcomes for patients with advanced HF in the past decade and have been used increasingly as bridge-to-transplantation (BTT) and destination therapies (DT).[1,5–8] Seco et al.[9] demonstrated equipoise in survival, acute rejection, or allograft vasculopathy in their meta-analysis of short- and long-term outcomes between OHT and BTT therapies. No further differences were demonstrated in postoperative mortality, stroke, renal failure, or bleeding.

Although the implantation of VAD is considered safe and effective, adverse events during VAD support can lead to poor outcomes and multiple readmissions, a costly consequence for the patient and the health care system alike. As experience with using BTT and DT as a VAD, it is possible that durable VAD therapy could afford patients similar outcomes compared with OHT, thereby decreas-

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Table I
Demographic characteristics of patients undergoing OHT versus VAD in NRD 2010–2014.

		OHT, *n* (%)	VAD, *n* (%)	*P* value
Discharges		5,440	6,671	
Sex				
	Male	4,049 (74)	5,214 (78)	.049
	Female	1,391 (26)	1,456 (22)	
Age		51.9 (±6.45)	55.5 (±6.60)	.018
Mean Elixhauser Index		5.74 (±1.08)	6.68 (±1.11)	.041
Payer				
	Medicare	1,966 (36)	3,141 (47)	<.001
	Medicaid	609 (11)	690 (10)	
	Private insurance	2,613 (48)	2,559 (39)	
	Self-pay	20 (0)	54 (1)	
	No charge	2 (0)	2 (0)	
	Other	182 (3)	177 (3)	
Median household income				
	Lowest (0–25)	1,352 (25)	1,778 (27)	.167
	Middle Low (26–50)	1,358 (25)	1,744 (27)	
	Middle High (51–75)	1,267 (24)	1,567 (24)	
	Highest (76–100)	1,371 (26)	1,459 (22)	
Hospital classification				
	Government	714 (13)	704 (11)	.105
	Nonprofit	4,713 (87)	5,912 (89)	
	Private	13 (0)	55 (1)	
Bed size				
	Small	156 (3)	104 (2)	<.001
	Medium	210 (4)	393 (6)	
	Large	5,075 (93)	6,173 (93)	
Comorbidities				
	Prior stroke	174 (3.2)	287 (4.3)	.138
	Hyperlipidemia	1,854 (34.1)	2,286 (34.3)	.931
	Angina	113 (2.1)	90 (1.3)	.188
	Coronary artery disease	2,087 (38.4)	2,629 (39.4)	.609
	Cardiogenic shock	1,687 (31)	3,448 (51.7)	<.001
	Endocarditis	535 (9.8)	1,259 (18.9)	<.001
	Prior CABG	74 (1.4)	154 (2.3)	.035
	Chronic lung disease	447 (8.2)	903 (13.5)	.012
	Peripheral vascular disease	215 (4)	357 (5.4)	.014
	Chronic kidney disease	2,000 (37)	3,023 (45)	<.001
	Chronic liver disease	101 (1.9)	102 (1.5)	.515
	Diabetes	306 (5.6)	426 (6.4)	.379
	Anemia	3,106 (57.1)	3,843 (57.6)	.839
	Coagulopathy	2,211 (40.6)	2,198 (33)	<.001
	Frailty	144 (2.6)	310 (4.6)	.005
	Obesity	547 (10.1)	1,071 (16.1)	<.001

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *CABG*, coronary artery bypass grafting.

ing the dependence on the transplant donor pool.[10] The present study was performed to compare resource utilization, mortality, and readmissions between patients receiving VAD and OHT, using a national cohort from 2010 to 2014.

Methods

Data source

The National Readmissions Database (NRD) is a nationally representative, all-payer inpatient administrative registry of acute care hospitals in the United States, provided by the Healthcare Cost and Utilization Project in sponsorship with the Agency for Healthcare Research and Quality. It contains more than 17 million discharges with appropriate hospital weights to estimate more than 36 million annual US hospitalizations from 2010 to 2014. Patient-level diagnostic and procedural data, hospital characteristics, and estimates of inpatient hospital supercharges were derived from the database. Additional estimates of hospital cost-to-charge ratios and diagnosis-related group (DRG) adjustments were utilized to estimate hospitalization costs and account for disease severity. This study was deemed exempt by the Institutional Review Board of the University of California, Los Angeles.

Study population

Adult patients undergoing isolated OHT or VAD placement between January through June annually from 2010 to 2014 were sampled from the NRD. Study cohorts were identified using the International Classification of Diseases, 9th edition, clinical modification (ICD-9 CM) procedural codes for OHT (37.51) and VAD (37.66). Patient and hospital identifiers were randomized within each year. Thus, data for 6-month readmission risk was calculated based on patients undergoing primary surgery during the first 6 months of each year of data in order to allow for uniform and adequate follow-up. Patients undergoing concomitant mitral valve surgery and coronary artery bypass graft were excluded. Comorbidities and complications associated with cardiovascular disease and cardiac surgeries were identified using previously validated ICD-9 CM procedure codes.

Study outcomes

The primary study outcomes of interest were inpatient mortality and 30-day readmission. Secondary outcomes included duration of stay, overall cost of hospitalization, and postoperative complications, including stroke, myocardial infarction, infection, and arrhythmia. The NRD provides hospital charges for each admission,

Table II
Trends in main outcomes (unadjusted) in National Readmission Database 2010–2014.

		2010	2011	2012	2013	2014	*P* value
Index admission cost	OHT (*n* = 5,440)	$140,851	$175,844	$166,997	$192,737	$206,793	.024
	VAD (*n* = 6,671)	$211,611	$210,819	$224,835	$215,978	$206,117	.005
Duration of stay, mean	OHT (*n* = 5,440)	31.1	31.6	31.6	40.1	41.7	.012
	VAD (*n* = 6,671)	38.2	36.1	37.2	36.1	34.8	.002
Index admission mortality	OHT (*n* = 5,440)	6.2%	4.5%	4.3%	3.9%	7.5%	.4741
	VAD (*n* = 6,671)	10.5%	8.2%	12.4%	10.1%	9.3%	.4647
Readmission, 30 days	OHT (*n* = 5,440)	27.5%	25.4%	23.9%	22.9%	21.3%	.4354
	VAD (*n* = 6,671)	23.2%	34.7%	27.5%	30.0%	27.4%	.092
Readmission, 6 months	OHT (*n* = 5,440)	52.2%	46.0%	44.9%	44.9%	42.2%	.3161
	VAD (*n* = 6,671)	58.6%	66.5%	60.6%	60.3%	63.4%	.4884

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device.

Table III
Main outcomes (unadjusted) in National Readmission Database 2010-2014.

	Heart replacement modality			Subgroup analysis		
	VAD (*n* = 6,671)	OHT (*n* = 5,440)	*P* value	OHT only (*n* = 3638)	OHT after BTT (*n* = 1,802)	*P* value
Index admission cost	$213,667	$177,128	.050	$186,709	$160,117	.032
Duration of stay, mean	36.3d	35.2d	<.001	40.0	26.5	<.001
Index admission mortality	10%	5.20%	<.001	5.7%	4.4%	.399
Readmission, 30 days	29%	24%	.005	24%	24%	.893
Readmission, 6 months	62%	46%	<.001	46%	45%	.689

OHT = orthotopic heart transplantation, VAD = ventricular assist device, BTT = bridge-to-transplant

which are often several times greater than the actual costs of care because of the complex nature of reimbursement. Thus, the cost was estimated for each patient, using hospital-specific charge-to-cost ratios provided by the Agency for Healthcare Research and Quality from the Centers for the NRD. These estimates were further adjusted for through the use of the Healthcare Cost and Utilization Project (HCUP) indices of the DRG to account for variance in severity of hospitalization.

Statistical analysis

Cost, duration of stay, mortality, and postoperative complications were estimated, using hierarchical multivariable regression controlling for patient demographics, comorbidities, and hospital characteristics. Patient-level demographic characteristics included age, race, insurance type, income, and comorbidity evaluated using the Elixhauser Index.[11] Additional comorbidities included angina; prior stroke; chronic renal, pulmonary, and liver disease; obesity, cardiogenic shock, coagulopathy, and frailty defined by ICD-9 codes.[10,12] Bed size, teaching, and geographic location (urban versus rural) were included to adjust for hospital variability in OHT and VAD performance.[5,13] Hierarchic regression adjusting for hospital covariance in the nested sampling design was utilized as recommended for the NRD database. Mortality, duration of stay, and log-transformed costs were modeled using logistic, Poisson, and linear distributions, respectively. Statistical analyses were performed using Stata 15 (StataCorp LP, College Station, TX).

Results

Patient demographics and clinical characteristics

During the study period, 12,111 patients were identified: 5,440 (45%) patients underwent OHT and 6,671 (55%) patients VAD implantation (Table I). Trend analysis demonstrated OHT rates to have increased marginally during the study, and rates of VAD implantation nearly doubled, surpassing OHT for the first time in 2011. VAD patients were more likely to be older (56 versus 52 years, $P < .018$), have a greater Elixhauser Index score (6.7 versus 5.7, $P = .041$), and be insured by Medicare. VAD patients were more likely to have comorbidities including chronic heart failure (CHF), cardiogenic shock, endocarditis, prior coronary artery bypass grafting (CABG), chronic kidney disease, chronic lung disease, and peripheral vascular disease. Patient income characteristics were not different among cohorts.

Outcomes and resource utilization

Overall, patients receiving a VAD had an increased duration of stay (36.3 days versus 35.2 days, $P = < 0.001$) (Table II). Inpatient mortality in patients receiving a VAD nearly doubled that of OHT patients (10% versus 5.2%, $P < .001$). Patients receiving a VAD also had slightly increased costs of index hospitalization ($213,667 versus $177,128, $P = .05$). Readmissions occurred frequently after VAD implantation and OHT, with greater rates at 30 days (29% versus 24%, $P = .005$) and 6 months (62% versus 46%, $P < .001$) for the VAD cohort.

In subgroup analysis comparing patients with OHT versus OHT after BTT, the two groups had similar index admission mortality and readmission rates (Table III). Patients with OHT bridged with VAD had lesser durations of stay (26.5 days versus 40 days, $P < .001$) and costs of the index admission ($160,117 versus $186,709, $P = .0321$). Among patients undergoing OHT from January to June in 2014, the year in which day of operation became available in the NRD, there was no difference in the average postoperative duration of stay between patients with OHT versus OHT after BTT (22.4 days versus 22.9 days, $P = .859$).

Patients who underwent VAD implantation had a 17% lesser comorbidity-adjusted duration of stay than those having OHT (IRR = 0.83, CI 0.82–0.84, $P < .001$) (Table IV). Compared to patients receiving Medicare, hospital stay was less for patients having private insurance (IRR = 0.96, CI 0.94–0.7, $P < .001$) and those with self-pay (IRR = 0.89, CI 0.84-0.95, $p < 0.001$). History of stroke, congestive heart failure, cardiogenic shock, peripheral vascular disease, chronic liver disease, diabetes, and frailty were associated with increased durations of hospital stay.

After adjusting for patient and hospital-level factors, the VAD cohort had more than a two-fold greater odds mortality compared

Table IV
Duration of stay adjusted for demographics, comorbidities and disease severity.

Patient-level covariates		IRR	*P* value
	OHT	ref	
	VAD	0.83 (0.82–0.84)	<.001
	Previous VAD	0.8 (0.79–0.81)	<.001
	Female	0.97 (0.96–0.98)	<.001
Age		1 (1–1)	.727
Elixhauser index		1.02 (1.02–1.03)	<.001
Insurance			
	Medicare	ref	-
	Medicaid	0.98 (0.97–1)	.080
	Private insurance	0.96 (0.94–0.97)	<.001
	Self-pay	0.89 (0.84–0.95)	<.001
	No pay	0.79 (0.65–0.96)	.019
	Other	0.9 (0.87–0.93)	<.001
Income quartile			
	Lowest (0-25)	ref	-
	Middle Low (26-50)	0.99 (0.97–1)	.066
	Middle High (51-75)	0.99 (0.97–1)	.170
	Highest (76-100)	1.01 (0.99–1.03)	.228
Comorbidity			
	Hypertension	0.82 (0.81–0.84)	<.001
	Hyperlipidemia	0.82 (0.81–0.83)	<.001
	Angina	0.93 (0.89–0.97)	.002
	CAD	1.01 (1–1.03)	.029
	CHF	0.99 (0.97–1.02)	.645
	History of MI	0.88 (0.87–0.9)	<.001
	AICD	1.11 (1.08–1.14)	<.001
	Cardiogenic shock	1.46 (1.45–1.48)	<.001
	Endocarditis	0.95 (0.94–0.97)	<.001
	Chronic kidney disease	0.99 (0.98–1)	.055
	Chronic pulmonary disease	0.94 (0.93–0.96)	<.001
	Peripheral vascular disease	1.11 (1.09–1.14)	<.001
	Chronic liver disease	1.08 (1.04–1.11)	<.001
	Diabetes	1.07 (1.05–1.09)	<.001
	Anemia	0.95 (0.94–0.96)	<.001
	Coagulopathy	0.99 (0.98–1.01)	.329
	Frailty	1.35 (1.32–1.39)	<.001
	High BMI (30+)	0.88 (0.86–0.89)	<.001
	History of stroke	1.41 (1.38–1.45)	<.001
Bed size			
	Small	ref	-
	Medium	1.31 (0.95–1.8)	.097
	Large	1.15 (0.86–1.55)	.341
Ownership			
	Government	ref	-
	Nonprofit	0.89 (0.78–1.01)	.079
	Private	0.71 (0.51–1)	.048
Teaching status			
	Non-teaching	ref	-
	Teaching	1.05 (0.84–1.31)	.652

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *IRR*, incidence rate ratio; *CABG*, coronary artery bypass grafting.

Table V
Outcomes of index admission mortality adjusted for demographics, comorbidities, and disease severity.

Patient-level covariates		OR	*P* value
	OHT	ref	
	VAD	2.22 (1.67–2.97)	<.001
	Previous VAD	0.85 (0.61–1.19)	.353
	Female	0.95 (0.71–1.28)	.748
Age		1.02 (1.01–1.03)	<.001
Elixhauser Index		0.96 (0.89–1.03)	.284
Insurance			
	Medicare	ref	
	Medicaid	0.84 (0.53–1.33)	.453
	Private insurance	0.83 (0.63–1.09)	.182
	Self-pay	1.88 (0.67–5.27)	.230
	Other	0.82 (0.4–1.68)	.593
Income quartile			
	Lowest (0–25)	ref	
	Middle low (26–50)	1.01 (0.71–1.43)	.957
	Middle high (51–75)	0.89 (0.62–1.28)	.542
	Highest (76–100)	1.07 (0.76–1.51)	.700
Comorbidity			
	Hypertension	0.5 (0.33–0.78)	.002
	Hyperlipidemia	0.36 (0.25–0.51)	<.001
	Angina	1.17 (0.4–3.4)	.778
	CAD	0.93 (0.68–1.26)	.637
	CHF	0.51 (0.31–0.83)	.007
	History of MI	0.56 (0.34–0.9)	.018
	AICD	0.14 (0.04–0.44)	.001
	Cardiogenic shock	1.48 (1.16–1.9)	.002
	Endocarditis	0.87 (0.6–1.26)	.457
	Chronic kidney disease	0.90 (0.67–1.22)	.498
	Chronic pulmonary disease	0.77 (0.49–1.22)	.266
	Peripheral vascular disease	1.99 (1.25–3.19)	.004
	Chronic liver disease	1.44 (0.59–3.5)	.426
	Diabetes	0.99 (0.56–1.72)	.959
	Anemia	0.63 (0.49–0.81)	<.001
	Coagulopathy	2.25 (1.74–2.91)	<.001
	Frailty	1.07 (0.59–1.93)	.820
	High BMI (30+)	1.05 (0.69–1.59)	.822
	History of stroke	5.17 (3.42–7.81)	<.001
Bed size			
	Small	ref	
	Medium	0.67 (0.24–1.83)	.431
	Large	0.76 (0.31–1.85)	.543
Ownership			
	Government	ref	
	Nonprofit	0.95 (0.67–1.34)	.754
	Private	0.78 (0.16–3.89)	.761
Teaching status			
	Teaching	2.10 (0.85–5.20)	.110

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *OR*, odds risk; *CABG*, coronary artery bypass grafting.

with patients treated with OHT (AOR = 2.22, CI 1.67–2.97, $P < .001$) (Table V). Increasing age was slightly associated with mortality (OR = 1.02, CI 1.01–0.03, <0.001). Sex, Elixhauser Index, income quartile, type of insurance, and hospital type were not predictors of death. Patients with a history of stroke, cardiogenic shock, peripheral vascular disease, and coagulopathy had increased odds of inpatient mortality (Table V).

Costs of index hospitalization associated with VAD implantation were 22% greater compared with OHT hospitalizations ($21,929, CI $17,836–$26,392, $P < .001$) (Table VI). Costs were not affected by patient income quartiles or type of insurance. Comorbidities associated with increased costs included history of stroke ($28,768, CI $19,279–$39,002, $P<.001$), cardiogenic shock ($28,262, CI $24,251–$32,400, $P < .001$), and automatic implantable cardioverter defibrillator (AICD) ($16,239, CI $7,834–$25,290, $P < .001$).

Compared with OHT, patients undergoing VAD implantation had an increased rate of postoperative supraventricular tachycardia (SVT)/atrial fibrillation (48% versus 37%, $P < .001$), myocardial infarction (6.9% versus 2.3%, $P < .001$), sepsis (12% versus 8.7%, $P = .024$), and urinary tract infections (17% versus 9%, $P < .001$) (Table VII). In contrast, patients having OHT had greater rates of postoperative pneumonia (9.3% versus 7.5%, $P < .0155$), and pneumothorax (4.6% versus 1.89%, $P < .001$).

Readmission

At 30 and 60 days, 1,312 (24%) and 2,499 (46%) VAD patients and 1,922 (29%) and 4,144 (62%) OHT patients were readmitted, respectively (Table VIII). Cost of readmission and duration of stay were significantly greater among VAD patients at 30 days and 6 months (Table VIII). Odds of readmission were not different at 30 days; however, readmission at 6 months was greater among the VAD cohort (OR = 1.60, CI 1.38–1.84, $P < .001$) after adjustment (Table IX). Patients with a history of hypertension, myocardial infarction, AICD, cardiogenic shock, and peripheral vascular disease had an increased odds of 6-month readmission. Age, type of

Table VI
Adjusted cost of care after OHT versus VAD during index admission.

Patient-level covariates		Cost	*P* value
	OHT	ref	
	VAD	$21,929 ($17,836–$26,163)	<.001
	Previous VAD	$–2,332 ($–5,988 to $1,462)	.225
	Female	$143 ($–3,216 to $3,617)	.934
Age		$16 ($–113 to $145)	.807
Elixhauser Index		$1,843 ($934–$2,760)	<.001
Insurance			
	Medicare	ref	
	Medicaid	$–1,660 ($–6621 to $3,559)	.526
	Private insurance	$–2,845 ($–5,902 to $310)	.077
	Self-pay	$–5,475 ($–19,523 to $10,978)	.492
	No pay	$17,782 ($–38,717 to $125,041)	.622
	Other	$–8,358 ($–15,679 to $–412)	.040
Income quartile			
	Lowest (0–25)	ref	
	Middle low (26–50)	$–1,221 ($–5,219 to $2,942)	.560
	Middle high (51–75)	$1,198 ($–2,975 to $5,547)	.579
	Highest (76–100)	$1,986 ($–2,335 to $6,495)	.373
Comorbidity			
	Hypertension	$–10,941 ($–14,503 to $–7,233)	<.001
	Hyperlipidemia	$–10,704 ($–13,610 to $–7,703)	<.001
	Angina	$3,661 ($–7,395 to $16,014)	.532
	CAD	$3,194 ($–543 to $7,069)	.095
	CHF	$3,658 ($–2,861 to $10,607)	.278
	History of MI	$–5,192 ($–9,492 to $–691)	.024
	AICD	$16,239 ($7,834–$25,290)	<.001
	Cardiogenic shock	$28,262 ($24,251–$32,400)	<.001
	Endocarditis	$–3,676 ($–7,634 to $449)	.080
	Chronic kidney disease	$–442 ($–4,007 to $3,254)	.812
	Chronic pulmonary disease	$–3,121 ($–7,598 to $1,570)	.189
	Peripheral vascular disease	$8,328 ($1,478–$15,632)	.016
	Chronic liver disease	$10,160 ($–1,285 to $22,912)	.084
	Diabetes	$334 ($–5,508 to $6,530)	.913
	Anemia	$–779 ($–3,839 to $2,376)	.624
	Coagulopathy	$4,547 ($1,280–$7,917)	.006
	Frailty	$19,327 ($10,414–$28,949)	<.001
	High BMI (30+)	$–3,656 ($–7,898 to $779)	.105
	History of stroke	$28,768 ($19,279–$39,002)	<.001
Bed size			
	Small	Ref	
	Medium	$98,797 ($54,308–$155,980)	<.001
	Large	$43,874 ($14,091–$81,325)	.002
Ownership			
	Government	ref	
	Nonprofit	$–18,178 ($–26,096 to $–9,431)	<.001
	Private	$–64,956 ($–74,417 to $–52,202)	<.001
Teaching status			
	Non-teaching	ref	
	Teaching	$11,507 ($–6,955 to $33,570)	.238

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *CABG*, coronary artery bypass grafting.

insurance, and income quartile did not affect odds of readmission (Table X).

Discussion

Although OHT remains the definitive treatment for end-stage HF, VAD technology has improved outcomes for patients with advanced HF in the past decade and has become an established treatment modality.[5–8] Outcomes with such pumps have improved because of advances in technology, operative technique, and post-implantation management. With increasing experience in the use of VAD as DT, morbidity and mortality for patients is expected to approach that of OHT, thus obviating the need to utilize limited organ resources. The present study compared trends in the management of advanced HF on a national level. More than a 5-year span from 2010 to 2014, our analysis demonstrated increased utilization of VAD implantation with the comparable cost of implantation and rates of 30-day and 6-month readmission between OHT and VAD.

Table VII
Complications during index hospital stay.

	OHT (%)	VAD (%)	*P* value
Valvular insufficiency	126 (2.3)	112 (1.7)	.235
Puncture	94 (1.7)	112 (1.7)	.920
Hemorrhage	740 (13.6)	1071 (16.1)	.122
Hematoma	269 (5.0)	295 (4.2)	.540
Dissection	4.2 (0.1)	3.4 (0.1)	.680
Stroke	70 (1.3)	116 (1.7)	.257
Supraventricular tachycardia	2023 (37)	3229 (48)	<.001
Atrioventricular block	195 (3.6)	172 (2.6)	.192
Shock	1018 (19)	1213 (19)	.572
Myocardial infarction	127 (2.3)	463 (6.9)	<.001
Pulmonary embolism	76 (1.4)	132 (2.0)	.195
Mural aneurysm	18.5 (0.34)	53 (0.80)	.139
DVT	155 (2.9)	203 (3.0)	.768
Pneumothorax	251 (4.6)	126 (1.89)	<.001
Pulmonary edema	65 (1.2)	64 (0.95)	.430
Pulmonary collapse	1168 (21)	1437 (22)	.970
Pneumonia	506 (9.3)	499 (7.5)	.016
Sepsis	478 (8.7)	768 (12)	.024
Wound infection	124 (2.3)	102 (1.5)	.076
Postoperative UTI	488 (9.0)	1135 (17)	<.001

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *DVT*, deep venous thrombosis; *UTI*, urinary tract infection.

The incidence of VAD implantation nearly doubled from 2010 to 2014; whereas the incidence of OHT increased only marginally, a trend that is consistent with previous analyses of national administrative data.[1] In our analysis, index hospitalization mortality after VAD implantation averaged 10% during the years 2010–2014, indicating that procedure-related mortality has continued to decrease after Mulloy et al.[14] reported its decrease from 40% to 18% from 2005 to 2009.[1,14] These decreases likely reflect the improvements being made in the field of mechanical circulatory assistance, postoperative and implantation follow-up, and the evolving demographic and comorbidity characteristics of patients.[15]

From 2010 to 2014, the OHT index hospitalization cost increased by 47% from $140,851 to $206,793, a trend that was consistent with Mulloy et al.,[14] who reported a 40% increase from $120,413 to $168,576. Our VAD index hospitalization cost remained stable during the study period at a mean of $213,000. Our estimates of the cost of implantation were consistent with more recent studies, including the estimates of Slaughter et al.[16] of $193,812 domestically. The decreased hospitalization costs of VAD implantation during the past decade are largely attributable to the improved technology of continuous flow pumps, which afford better reliability, lesser rates of pump exchange, and lesser rates of infectious complications.[16]

A major contributor to the costs of index hospitalization is the duration of stay. Average hospitalization of the index admission for VAD implantation was 36 days compared with 35 days in patients receiving OHT. Notably, our analysis indicated that the average stay for VAD implantation decreased from 38 days to 35 days from 2010 to 2014, whereas stay for OHT increased from 31 days to 42 days. Our 36-day average duration of stay for VAD implantation is greater than the 20-day average stay reported in previous analyses, which had smaller sample sizes.[17,18] History of mechanical circulatory support did not impact the post-operative stay in patients undergoing OHT. Despite a shorter total hospital stay, patients with OHT bridged with VAD had a similar post-operative stay compared with OHT patients without bridging. These findings are similar to other studies detailing outcomes of BTT with VAD.[19–21] The lesser pre-operative period in the OHT after BTT group may reflect

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Table VIII
Readmission outcomes after VAD versus OHT.

	OHT	VAD	*P* value
30-Day readmission			
no.	1312 (24)	1922 (29)	.005
Cost	$21,586 ($18557–$24,614)	$29,115 ($24,285–$33,944)	<.001
Duration of stay	6.81 (6.01–7.61)	10.1 (8.92–11.2)	.018
6-Month readmission			
no.	2499 (46)	4144 (62)	<.001
Cost	$20,144 ($17,705–$22,583)	$34,878 ($30,552–$39,204)	.011
Duration of stay	6.28 (5.66 –6.89)	10.4 (9.45.–11.2)	.025

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device.

Table IX
Readmission: 30-day and 6-month outcomes adjusted for demographics, comorbidities, and disease severity.

		30-Day readmission		6-Month readmission	
Patient-level covariates		OR	*P* value	OR	*P* value
	OHT	ref		ref	
	VAD	1.02 (0.88–1.2)	.762	1.6 (1.38–1.84)	<.001
	Previous VAD	0.89 (0.74–1.07)	.208	0.83 (0.7–0.98)	.026
	Female	1.11 (0.94–1.3)	.228	1.42 (1.22–1.65)	<.001
Age		1 (1–1.01)	.450	1 (0.99–1)	.290
Elixhauser Index		1.05 (1.01–1.09)	.020	1.04 (1–1.08)	.067
Insurance					
	Medicare	ref		ref	
	Medicaid	0.84 (0.65–1.08)	.165	1.01 (0.8–1.26)	.953
	Private insurance	0.88 (0.75–1.03)	.103	0.93 (0.8–1.07)	.290
	Self-pay	0.92 (0.42–2.01)	.833	0.66 (0.33–1.34)	.256
	No Pay	2.91 (0.17–48.31)	.457	–	-
	Other	0.6 (0.38–0.93)	.021	0.62 (0.43–0.89)	.009
Income quartile					
	Lowest (0–25)	ref		ref	
	Middle low (26–50)	1.08 (0.89–1.31)	.429	1.02 (0.85–1.22)	.839
	Middle high (51–75)	0.95 (0.78–1.16)	.624	0.89 (0.74–1.06)	.196
	Highest (76–100)	0.82 (0.67–1)	.048	0.84 (0.7–1)	.051
Comorbidity					
	Hypertension	0.8 (0.66–0.98)	.031	0.85 (0.71–1.01)	.070
	Hyperlipidemia	1.02 (0.87–1.2)	.793	1.14 (0.98–1.31)	.086
	Angina	1.41 (0.85–2.35)	.188	1.25 (0.76–2.07)	.381
	CAD	1.04 (0.87–1.25)	.637	1.12 (0.95–1.32)	.173
	CHF	0.91 (0.67–1.25)	.572	0.9 (0.68–1.19)	.453
	History of MI	1.05 (0.84–1.31)	.660	1.06 (0.86–1.3)	.579
	AICD	1.21 (0.85–1.71)	.294	1.02 (0.73–1.42)	.917
	Cardiogenic shock	1 (0.87–1.16)	.998	0.89 (0.78–1.02)	.096
	Endocarditis	0.83 (0.68–1.02)	.077	0.83 (0.69–0.99)	.04
	Chronic kidney disease	1.02 (0.86–1.21)	.834	1.03 (0.88–1.21)	.74
	Chronic pulmonary disease	1.16 (0.93–1.45)	.184	1.28 (1.04–1.59)	.022
	Peripheral vascular disease	0.78 (0.57–1.09)	.142	0.83 (0.62–1.11)	.201
	Chronic liver disease	0.94 (0.55–1.59)	.805	0.93 (0.58–1.51)	.783
	Diabetes	0.84 (0.62–1.13)	.245	1.12 (0.86–1.46)	.416
	Anemia	1.05 (0.91–1.21)	.523	1.17 (1.02–1.33)	.021
	Coagulopathy	0.83 (0.71–0.97)	.021	0.83 (0.72–0.95)	.007
	Frailty	1.42 (1–2.01)	.052	1.55 (1.09–2.2)	.015
	High BMI (30+)	0.94 (0.76–1.17)	.571	0.99 (0.81–1.21)	.934
	History of stroke	0.78 (0.53–1.16)	.226	0.69 (0.49–0.97)	.031
Bed size					
	Small				
	Medium	2.75 (1.49–5.07)	.001	2.72 (1.55–4.77)	<.001
	Large	1.95 (1.12–3.42)	.019	2.14 (1.3–3.51)	.003
Classification					
	Government				
	Nonprofit	0.92 (0.75–1.11)	.378	0.9 (0.73–1.1)	.287
	Private	0.8 (0.31–2.07)	.651	0.68 (0.28–1.65)	.393
Teaching status					
	Non-teaching				
	Teaching	1.28 (0.86–1.91)	.223	0.95 (0.64–1.4)	.79

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *CABG*, coronary artery bypass grafting.

systemic differences in communication and follow-up practices enabling patient admission just before the transplant.

Our analysis demonstrated that postoperative bleeding, cardiac complications, including arrhythmias and MI, pneumothorax, and infectious complications after VAD implantation were common. Our findings were similar to previous literature examining post-implantations complications.[2,14,16,22–24] Akhter et al.[25] found postoperative bleeding led to an additional 3 days, infections an additional 5 days, and cardiac complications an additional 7 days in hospital stay.[25] Slaughter et al.[16] estimated that each of the

Table X
Primary causes of readmission by replacement modality.

30-Day readmission				6-Month readmission			
OHT (*n*=1,312)		VAD (*n*=1,922)		OHT (*n*=2,499)		VAD (*n*=4,144)	
Complications of transplanted heart	387 (31.0%)	Acute on chronic systolic heart failure	188 (9.7%)	Complications of transplanted heart	586 (23.5%)	Infection because of VAD	322 (7.8%)
Postoperative infection (septicemia, influenza, pneumonia, C diff colitis, UTI)	101 (7.7%)	Gastrointestinal tract bleed	151 (7.8%)	Postoperative infection (septicemia, influenza, pneumonia, C diff colitis, UTI)	197 (8.0%)	Acute on chronic systolic heart failure	306 (7.5%)
Acute kidney failure	51 (3.9%)	VAD mechanical complications	102 (5.9%)	Acute kidney failure	112 (4.5%)	VAD mechanical complications	361 (7.9%)
Pulmonary embolism and infarction	31 (2.4%)	Paroxysmal ventricular tachycardia	112 (5.8%)	Pulmonary embolism	36 (1.4%)	Paroxysmal ventricular tachycardia	174 (4.2%)
Seroma	30 (2.2%)	Infection due to VAD	70 (3.6%)	Seroma	33 (1.3%)	Gastrointestinal tract bleed	313 (7.6%)
Cardiac dysrhythmias	16 (2.1%)	Abnormal coagulation profile	68 (3.5%)	Other pulmonary embolism and infarction	36 (1.4%)	Chronic ischemic heart disease	115 (2.8%)
Disruption of surgical wound	22 (1.7%)	Other postoperative infection	58 (3%)	Complications of transplanted kidney	29 (1.2%)	Abnormal coagulation profile	94 (2.3%)
Gastrointestinal bleed	25 (1.9%)	Unspecified transient cerebral ischemia	32 (1.7%)	Disruption of surgical wound	24 (0.9%)	Unspecified cerebral artery occlusion	55 (1.3%)

OHT, orthotopic heart transplantation; *VAD*, ventricular assist device; *C diff*, clostridium difficile; *UTI*, urinary tract infection.

post-implantation complications led to an incremental increase in cost ranging between $22,000 and $53,000. These figures highlight the need for meticulous perioperative management and the development and dissemination of best practices to decrease costs and durations of hospital stay.

All-cause HF readmission at 30 days has been estimated to be as low as 6% in previous studies.[26] Compared with patients who underwent OHT, patients receiving a VAD had a 5% and 16% greater rate of readmission after 30 days and 6 months, respectively. Our 29% cumulative incidence of readmission within 30 days after discharge after VAD implantation is less than the 44% reported by Akhter et al.[25] and comparable to the 22% reported by Hasin et al.[27] Our 62% 6-month readmission incidence after VAD implantation is also similar to the 55.6% reported by Hasin et al.[27] and the 79% reported by Forest et al.[28] Compared with the OHT cohort, average cost of readmission was 34% ($7,529) greater at 30 days and 73% ($14,734) greater at 6 months among VAD patients. As reported in similar studies,[22,24,25] common causes of readmission in VAD patients included mechanical complications and infections of the VAD, HF, cardiac arrhythmias, and gastrointestinal bleeds. To curtail VAD readmission rates and associated costs, it is important to evaluate timing and causes of readmission in order to implement cost-effective measures to address common causes and focus on prevention. Given the projected increases in VAD utilization and the limited pool of transplant donors, these measures are essential to the viability of such therapy in the era of value-based health care delivery.

Limitations

This study was subject to the limitations consistent with retrospective, aggregated, administrative data. The identification of diseases and procedures was limited to variables that were available in the registry based on ICD-9 coding. The NRD is limited to inpatient admissions only. Duration of stay post-operatively is not separated from total duration of stay for years before 2014 included in the analysis. VAD model or mechanism and subsequent management were not systematically captured despite recognized differences in left versus right ventricular support, technology generation, BTT, and pharmacologic support. Furthermore, the granularity of data was limited to diagnostic and procedural data. Race, laboratory values, imaging, and medical therapy were unavailable in the NRD. Complications after transplant are combined in a single complication code limiting identification of types of rejection or incidence of opportunistic infection. Although patient records were linked for multiple hospitalizations within an annual period, outpatient evaluations, emergency room visits, and access to pharmacy data were not included in the database.

In conclusion, during a 5-year span from 2010 to 2014, nationwide rates of VAD implantation doubled and index hospitalization mortality after VAD implantation averaged 10%, nearly 4 times less than the 42% mortality reported in 2005.[1] Implant hospitalization costs have also appreciably decreased in the past decade, with improved technology of continuous flow pumps. Nonetheless, 30-day and 6-month rates of VAD patient readmission remain greater than their OHT counterparts. Given the projected increases in VAD utilization and the limited transplant donor pool, further emphasis on cost containment and decreased rates of readmissions after VAD implantation is essential to the viability of such therapy in the era of value-based health care delivery.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.surg.2018.04.013.

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