In-hospital mortality in older patients after ventricular assist device implantation: A national cohort study

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ABSTRACT

Objectives: To assess baseline patient characteristics and identify factors associated with in-hospital mortality after ventricular assist device (VAD) placement.

Methods: Cross-sectional study using the National Inpatient Sample database from January 2010 to December 2014. Analyses were performed with sample weights provided by the National Inpatient Sample, which are reported $\pm$ the standard error of the mean.

Results: Weighted samples yielded $15,021 \pm 1111$ patients who received a VAD. The mean age at time of implantation was 56.6 years. Most recipients were white (59.9%) and male (75.0%). Among older patients, in-hospital mortality increased from 17.2% to 48.2% when 1 or more high-risk interventions (cardiac surgery, prolonged mechanical ventilation, hemodialysis, or extracorporeal membrane oxygenation) preceded VAD placement ($P < .001$). In comparison, in-hospital mortality in younger patients increased from 11.1% to 29.4% when 1 or more of these same procedures preceded VAD placement. The mortality difference associated with these procedures was 19% greater in older patients compared with younger patients (95% confidence interval [CI], 9%-28%). In-hospital mortality among VAD recipients was associated with age older than 65 years (odds ratio [OR], 1.76; 95% CI, 1.29-2.40), female sex (OR, 1.27; 95% CI, 0.97-1.67), and at least 1 high-risk intervention preceding VAD (OR, 5.52; 95% CI, 4.27-7.13).

Conclusions: Older patients who underwent 1 or more intensive treatments before VAD placement had a nearly 50% inpatient mortality and were unlikely to receive a cardiac transplantation. Refining patient selection might help better align VAD with those most likely to benefit. (J Thorac Cardiovasc Surg 2019;158:466-75)

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Central Message

Older adults who undergo intensive treatments before VAD implantation have a 48.2% inpatient mortality.

Perspective

We assessed outcomes after VAD placement in older adults. Older adults who underwent intensive treatments (cardiac surgery, mechanical ventilation, hemodialysis, or ECMO) before VAD implantation had a 48.2% mortality rate and are unlikely to receive cardiac transplantation. Refining patient selection might help better align treatment with those most likely to benefit.

See Commentaries on pages 476 and 478.

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Ventricular assist devices (VADs) have emerged as an alternative to transplantation for the >250,000 patients in the United States with end-stage heart failure.¹ Improved technology has made VAD, and especially left VAD (LVAD), implantation a treatment option for an increasing number of patients, particularly in older adults who are unlikely to receive a heart transplantation.² The proportion of LVADs

Scanning this QR code will take you to the article title page to access supplementary information.

Abbreviations and Acronyms

AHRQ	= Agency for Healthcare Research and Quality
CI	= confidence interval
ECMO	= extracorporeal membrane oxygenation
ICD-9	= International Classification of Diseases, Ninth Revision
ICD-9-PCS	= International Classification of Diseases, Ninth Revision, Procedural Coding System
IABP	= intra-aortic balloon pump
INTERMACS	= Interagency Registry for Mechanically Assisted Circulatory Support
LVAD	= left ventricular assist device
NIS	= National Inpatient Sample
OR	= odds ratio
VAD	= ventricular assist device

placed as destination therapy increased from 14.7% in 2006 to 49.7% of all LVAD placements in 2014.³ At the same time, the number of heart transplantations has remained stable and relatively uncommon in older adults. Currently, only 15% of heart transplantations are performed in adults older than the age of 65 and less than 2% in adults older than the age of 70 years.^{4,5}

Compared with medical management, VADs improve quality of life, symptoms, and longevity in younger and older patients.⁶⁻⁹ However, adverse outcomes such as stroke, gastrointestinal bleeding, early mortality, and rehospitalization are more common among older patients.^{7,10} Furthermore, increased frailty and comorbidities might attenuate the benefit of VAD therapy. VAD therapy requires substantial caregiving, which might be more challenging when the primary caregiver is another older adult. The decision to implant a VAD involves complex trade-offs, and can exert a great effect on patients and families.^{11,12} The expense is also significant, with a mean procedure cost of \$234,808 in 2011, which is most often paid for by Medicaid and Medicare plans.¹³ An improved understanding of VAD implantation, including hospital outcomes might identify opportunities to optimize patient selection and thereby improve quality by lowering mortality, minimizing unnecessary suffering, increasing access, and reducing cost.

Previous studies have shown increased risk of early mortality after VAD implantation in patients older than the age of 65 years.¹⁴ In addition, patients who require hemodialysis, intubation, or who undergo same-admission cardiac surgery before VAD placement have an increased risk of early mortality.^{8,15} We hypothesized that in older

patients, intensive treatments before VAD placement would result in a greater increase of in-hospital mortality compared with younger patients. We used the National Inpatient Sample (NIS) to compare younger and older patients receiving VADs over a 5-year period (2010-2014). Specifically, we analyzed: (1) demographic and clinical characteristics; (2) differences in hospital course, mortality, and disposition; and (3) temporal trends in the number of VADs placed. We captured and compared the effects of intensive treatments before VAD placement. These treatments included prolonged intubation (>96 hours), hemodialysis, intra-aortic balloon pump (IABP), same-admission cardiac surgery, and extracorporeal membrane oxygenation (ECMO).

METHODS**Data Source**

We used the NIS, which is the largest publicly available all-payer inpatient health care database in the United States, yielding national estimates of diagnoses, procedure utilization, and outcomes for hospital inpatient stays from a 20% stratified sample of US hospitals and is part of the Healthcare Quality and Utilization Project.¹⁶ The database contains a nationally representative sample from more than 7 million hospitalizations annually. Applying sample weights provided by the NIS, the database projects estimates for more than 36 million hospitalizations annually. The NIS provides data on patient demographic characteristics, in-hospital clinical outcomes, hospital characteristics, and hospital charges. Federal hospitals are not included in the NIS. Quality control and validation of the NIS are performed by the Agency for Healthcare Research and Quality (AHRQ). For all demographic variables, except race/ethnicity, there is <1% missing data. Missing race/ethnicity was categorized as “unknown” in our results. Data from the NIS has been used to describe patterns of health care usage and outcomes of major procedures.^{17,18} In addition, data from the NIS has been previously validated in the study of VAD and congestive heart failure.¹³ The database was provided with deidentified patient information and thus deemed exempt from institutional review by the Human Research Committee at Partners HealthCare.

Study Sample and Primary Outcomes

We included all individuals ≥ 18 years old who received a VAD during a hospitalization between January 1, 2010 and December 31, 2014. VAD was defined by the International Classification of Diseases, Ninth Revision, Procedural Coding System (ICD-9-PCS) code for VAD placement (37.66). This code is specific to implantation of a durable VAD and excludes temporary procedures such as pulsation balloons and percutaneous external heart assist devices as well as total internal biventricular heart replacement. This code has been stable in its usage throughout the study period. Use of this ICD-9-PCS code to identify patients who received a VAD has been previously validated in several studies.^{13,19} We excluded patients who underwent a heart transplantation (ICD-9-PCS code 37.51) or combined heart-lung transplantation (ICD-9-PCS code 37.51) during same admission as VAD placement. The primary outcome of this study was in-hospital mortality. Secondary outcomes included length of hospital stay and hospital charges.

Covariates

Demographic covariates included age, sex, race/ethnicity, primary insurance type, and median income quartile on the basis of zip code. Race/ethnicity was reclassified as non-Hispanic white, non-Hispanic black, other (Hispanic, Asian, and Native American), and unknown. Other covariates included type of admission and geographic region (Northeast, Midwest,

South, and West). Comorbidities were defined using International Classification of Diseases, Ninth Revision, Clinical Modification codes and the Elixhauser comorbidity index. The Elixhauser Index used in this study is a well validated indicator of comorbidities and was designed specifically to measure hospital charges, length of stay, and in-hospital mortality, which were the primary and secondary outcomes of this study. Furthermore, the Elixhauser Index was developed and validated using AHRQ data using the same variables that are reported in the NIS database (also maintained by AHRQ).²⁰ In this study, Elixhauser comorbidities were generated from International Classification of Diseases, Ninth Revision, Clinical Modification diagnosis codes using AHRQ Comorbidity Software.²¹

Age Stratification

Previous reports focusing on in-hospital factors associated with mortality after VAD placement have dichotomized at the age of 65 years.¹⁴ To determine the validity of dichotomization, we treated age as a continuous variable and used a logistic regression model to plot age against probability of in-hospital mortality after VAD implantation (Figure 1). We determined that mortality risk as a function of age is relatively stable until the age of 65 years, at which point it begins to dramatically increase. Because of the previous categorization of age within the literature and the findings in our regression we chose to categorize age into younger (18-65) and older (>65) categories.

In-Hospital Treatments

Circulatory support and co-therapy were identified using ICD-9 codes listed in Table E1. All hospital charges were adjusted for inflation with reference to 2014 US dollars, using the latest Consumer Price Index data (<http://www.usinflationcalculator.com>).

VAD surgery date and admission date were used to determine intensive procedures or treatments that occurred 1 hospital day before VAD

placement. A 1 hospital day cutoff was used to ensure invasive treatments directly related to the VAD implantation (eg, mechanical ventilation during surgery) were not included in the analysis. Inpatient intensive procedures or treatments received during admission before VAD implantation were identified using ICD-9 procedure codes. These included IABP, cardiac surgery, mechanical ventilation, hemodialysis, and ECMO. In the case of cardiac surgery, we identified surgeries on the basis of ICD-9 procedure codes, which are listed in Table E1. We included open and endovascular procedures involving the valves and septa, coronary vessels, cardiectomy, pericardiectomy, and ascending aorta.

Statistical Analysis

All analyses were performed using SAS version 9.4 (SAS Institute Inc, Cary, NC). Frequencies, proportions, and 95% confidence intervals (CIs) were calculated and weighted to reflect national estimates using inverse sampling weights provided by the NIS. Trend weights were used for 2010-2011 NIS data to adjust for the redesign in 2012. χ^2 Tests were used to compare the demographic and clinical characteristics. Continuous variables, such as length of stay and hospital charges, were compared using Wilcoxon rank sum test. Multivariable logistic regression was used to identify associations with in-hospital mortality. We used a model that included all patient demographic characteristics, hospital factors, and comorbidities measured using the Elixhauser comorbidity index. To avoid collinearity we combined preimplantation interventions with significant clinical overlap into a single high-risk intervention variable. Difference-in-difference analysis was used to compare the effects of preoperative interventions on mortality in older and younger patients. Finally, χ^2 tests and Wilcoxon rank sum tests were used to compare temporal trends of VAD use, in-hospital mortality, and hospital charges from 2010 to 2014. A 2-tailed $P < .05$ was considered to indicate statistical significance.

FIGURE 1. Plot of predicted probability of death after ventricular assist device placement in a logistic regression model with age as a continuous variable. Bars around central line represent upper and lower limits of 95% confidence intervals.

RESULTS

Study Population

Results are expressed as weighted samples $\pm$ the standard error of the mean. We identified 15,021 $\pm$ 1111 episodes of VAD implantation. The demographic

characteristics, clinical characteristics, and hospital course of patients receiving a VAD are presented in Table 1. Most of the recipients were white (59.9%) and male (75.0%). The average score on the Elixhauser Comorbidity Index was 3.60 $\pm$ 0.07. Individual components of the

TABLE 1. Patient characteristics

	Overall (n = 15,021 $\pm$ 1111)		Ages 18-65 years (n = 10,790 $\pm$ 782)		Ages > 65 years (n = 4231 $\pm$ 329)		P value
	Value	SE	Value	SE	Value	SE	
Mean age, y	56.6	0.27	—	—	—	—	—
Male sex, n (%)	11,481 (76.4)	827	7919 (73.4)	593	3562 (84.2)	286	<.001
Elixhauser index, mean	3.61	0.07	3.53	0.08	3.8	0.10	<.001
Emergency department admission, n (%)	9778 (65.1)	706	7155 (66.4)	518	2623 (62.1)	235	.03
Race, n (%)							
Non-Hispanic white	8995 (59.9)	696	5930 (55.0)	494	3065 (72.4)	260	<.001
Black	3227 (21.5)	279	2847 (26.4)	252	380 (9.0)	49	
Other*	1754 (11.7)	222	1324 (12.3)	163	430 (10.2)	74	
Unknown	1045 (6.9)	168	689 (6.4)	116	356 (8.4)	65	
Primary payer, n (%)							
Medicare	7282 (48.5)	529	3684 (34.1)	295	3598 (85.0)	283	<.001
Medicaid	1666 (11.1)	154	1636 (15.2)	151	30 (0.7)	12	
Private insurance	5426 (36.1)	415	4895 (45.4)	377	530 (12.5)	65	
Other†	523 (3.5)	79	461 (4.3)	71	62 (1.5)	19	
Household income quartile, n (%)							
First (highest income)	4078 (27.1)	343	2212 (20.9)	232	1154 (27.8)	140	<.001
Second	3659 (24.4)	289	2440 (23.0)	204	1215 (29.3)	112	
Third	3655 (24.3)	285	2760 (26.0)	237	900 (21.7)	83	
Fourth (lowest income)	3366 (22.4)	332	3196 (30.1)	276	883 (21.3)	100	
Hospital region, n (%)							
Northeast	3009 (20.0)	467	2046 (19.0)	328	962 (22.7)	180	.01
Midwest	3812 (25.4)	556	2740 (25.4)	426	1072 (25.3)	151	
South	6063 (40.4)	670	4576 (42.4)	512	1487 (35.1)	186	
West	2137 (14.2)	368	1428 (13.2)	248	709 (16.8)	136	
Discharge disposition, n (%)							
Home	3902 (26.0)	364	3185 (29.5)	297	716 (16.9)	95	<.001
Home care	3573 (23.8)	394	2112 (19.6)	265	1462 (34.6)	166	
Health care facility	5608 (37.3)	457	4284 (39.7)	363	1323 (31.3)	140	
Died	1933 (12.9)	175	1204 (11.1)	120	729 (17.2)	81	
Mean length of stay, d							
Alive at discharge	33.2	0.68	33.3	0.72	33.2	1.01	.94
Died	39.0	1.89	41.9	2.44	34.3	2.42	.03
Mean hospital charges, USD							
Alive at discharge	767,431	21,023	761,354	21,367	784,155	28,579	.52
Died	1,037,622	49,259	1,065,777	64,374	991,547	58,889	.39
Interventions before VAD implantation, n (%)							
IABP	3278 (21.8)	332	2343 (22.8)	220	935 (19.5)	112	.07
Cardiac surgery‡	557 (3.7)	86	392 (3.6)	52	165 (3.9)	34	.62
Mechanical ventilation	1250 (8.3)	151	969 (9.0)	104	281 (6.6)	47	<.001
ECMO	526 (3.5)	82	431 (4.0)	61	95 (2.2)	21	<.001
Hemodialysis	575 (3.8)	96	332 (3.2)	52	243 (5.1)	44	.01

SE, Standard error of the mean of the weighted sample; VAD, ventricular assist device; IABP, intra-aortic balloon pump; ECMO, extracorporeal membrane oxygenation. *Includes Hispanic, Asian or Pacific Islander, Native American, and other. †Includes self-pay, no charge, and other. ‡Includes 5 major groups of surgeries operations on valves and septa, vessels of heart, cardiomy and pericardiomy, pericardiomy and excision of lesion of heart, and major aortic dissection or aneurysm repair.

Elixhauser Comorbidity Index are listed in [Table E2](#). More than half of the patient population presented through the emergency department (65.1%) and a large percentage were covered either through Medicare (48.5%) or private insurance (36.1%). Overall, mortality was 12.9%; however, nearly half were able to be discharged home without services, or home with additional home care (49.8%). The average length of stay was 33.2 ± 0.68 days for patients who were alive at discharge and 39.0 ± 1.89 days for those who died in-hospital. Similarly, mean hospital charges were $\$767,431 \pm \$21,023$ for patients alive at discharge and $\$1,037,622 \pm \$49,259$ for those who died in-hospital. Finally, the most common preoperative procedure was IABP, which was performed in approximately 1 in 5 patients. Other major preoperative interventions including prolonged mechanical ventilation, ECMO, hemodialysis, and same-admission cardiac surgery occurred in <10% of the study population.

Relation of Age and Mortality

In stratified analysis, all differences between the age groups were statistically significant ([Table 1](#)). Compared with patients ages 18–65 years, older VAD recipients were more likely to be white (72.4% vs 55.0%; $P < .001$) and male (84.2% vs 73.4%; $P < .001$). Older VAD recipients had a higher Elixhauser index score (3.80 vs 3.53; $P < .001$). Regional utilization differences also existed, with a higher proportion of older patients receiving a VAD in the West (16.8% vs 13.2%; $P < .001$) and Northeast (22.7% vs 19.0%; $P < .001$). Patients ages 18–65 years were more likely to have been admitted through the emergency department (66.4% vs 62.1%; $P = .03$). The mean length of stay was >30 days in both groups. Patients ages 18–65 years who died in-hospital had a longer mean length of stay than patients older than 65 years who died in-hospital (41.9 vs 34.3 days; $P = .03$). Total hospital charges were similar in both groups. In both age groups, a significant proportion of patients underwent invasive treatments before VAD placement, which included IABP, cardiac surgery, mechanical ventilation >96 hours, ECMO, and hemodialysis. Among these treatments patients between the ages of 18 and 65 years tended to have a high rate of prolonged mechanical ventilation (9.0% vs 6.6%; $P < .001$) and use of ECMO (4.0% vs 2.2%; $P < .001$). Conversely, those aged 18–65 years had a significantly lower rate of hemodialysis (3.2% vs 5.1%; $P = .01$).

Preoperative Interventions and Mortality

In-hospital mortality for patients older than 65 years was significantly higher than in patients ages 18–65 years (17.2% vs 11.1%; $P < .001$). In-hospital mortality among patients who received intensive procedures/treatments during the index admission before VAD implantation surgery, stratified according to age, is shown in [Table 2](#) and

[Figure 2](#). The 4 procedures/treatments most highly correlated with inpatient mortality were same-admission cardiac surgery, hemodialysis, mechanical ventilation, and ECMO. Among patients older than 65 years, 649 ± 83 (15.3%) had at least 1 of these procedures, before VAD implantation. Of these patients, 313 ± 52 (48.2%) died during hospitalization. For patients ages 18–65 years, 1694 ± 169 (15.7%) had 1 of these 4 procedures before VAD implantation. Of these patients, 498 ± 65 (29.4%) died during hospitalization. Although having 1 of these procedures increased mortality in younger and older patients, there was a significantly greater increase in mortality in patients older than 65 years.

In our multivariable logistic regression model the 4 highest risk interventions (same-admission cardiac surgery, hemodialysis, mechanical ventilation >96 hours, and ECMO) were combined into a high-risk treatment category to avoid collinearity. These high-risk treatments were associated with increased in-hospital mortality (odds ratio [OR], 5.52; 95% CI, 4.27–7.13). Univariate analysis is reported separately in [Table E3](#). Age older than 65 years was also associated with increased in-hospital mortality (OR, 1.77; 95% CI, 1.29–2.40; [Table 3](#)). However, we did not see a significant interaction effect between age older than 65 years and high-risk treatments in multivariate analysis ($P = .24$). Elective admission (as opposed to admission through the emergency department) was associated with lower odds of mortality (OR, 0.75; 95% CI, 0.57–0.98). In multivariate regression, IABP was not associated with a significant change in overall mortality (OR, 0.91; 95% CI, 0.69–1.20). Because of the categorization of age we performed a sensitivity analysis using age as a continuous variable. There were no changes to the major trends and minimal change in the reported ORs.

Temporal Trends in Heart Transplantation and VAD Placement According to Age

The number of VAD implantations per year in patients ages 18–65 years increased from 1808 ± 459 in 2010 to 2560 ± 317 in 2014 ([Figure 3](#)). The number of VAD implantations per year in patients older than 65 years more than doubled with 532 ± 143 in 2010 to 1100 ± 120 in 2014. In-hospital mortality during this period did not significantly change on the basis of age. The rate of heart transplantations declined steadily with age. Of nearly 10,000 heart transplantations, only 1515 (15.1%) were performed in individuals older than the age of 65 years ([Figure 4](#)). By the age of 71 years, this number decreased to 229 (2.2%), indicating that most of the 2025 ± 198 patients with a VAD older than the age of 71 years were unlikely to receive heart transplantation.

DISCUSSION

The objective of this study was to analyze the baseline demographic characteristics and characteristics of patients

TABLE 2. Difference-in-difference analysis of mortality according to intervention in patients before receipt of VAD

	Ages 18-65 years		Age older than 65 years		Mortality difference (95% CI)
	Died (% receiving treatment)	SE	Died (% receiving treatment)	SE	
IABP	350 (15.0)	48	150 (16.2)	31	1.0% (−5.0-7.0)
Cardiac surgery*	76 (19.5)	19	68 (41.1)	20	22% (5.0-39)
Mechanical ventilation	263 (27.1)	40	113 (40.1)	24	13% (1.0-26)
ECMO	183 (42.4)	34	50 (52.4)	16	10% (−15-34)
Hemodialysis	159 (47.8)	33	173 (71.1)	34	23% (4.0-42)
At least 1 intervention excluding IABP†	498 (29.4)	65	313 (48.2)	52	19% (9.0-28)
Baseline in-hospital mortality after VAD implantation	1204 (11.1)	120	729 (17.2)	81	6.1% (+5.3-7.1)

Mortality difference is the change in mortality between each age group in those who received the indicated treatment. *SE*, Standard error of the mean; *CI*, confidence interval; *IABP*, intra-aortic balloon pump; *ECMO*, extracorporeal membrane oxygenation; *VAD*, ventricular assist device. *Includes 5 major groups of surgeries: operations on valves and septa, vessels of heart, cardiomy and pericardiomy, pericardiomy and excision of lesion of heart, and major aortic dissection or aneurysm repair. †High-risk intervention defined by cardiac surgery, mechanical ventilation (>96 hours), ECMO, or hemodialysis before VAD placement, all of which are associated with high in-hospital mortality.

receiving VADs and determine the effect of preimplantation interventions on in-hospital mortality. We found that in-hospital mortality after VAD placement begins to rapidly increase in patients older than the age of 65 years. Although previous studies have reported increasing age to be a risk factor for early mortality,^{8,14,19} our study shows an explanation for this finding. Intensive procedures before VAD placement resulted in a nearly 50% in-patient mortality in older patients. Finally, this work confirmed a low rate of cardiac transplantations in patients older than the age of 65 years, indicating that most VAD placements in this older age group was destination therapy rather than a bridge to transplantation (Graphical Abstract). The high rate of in-patient mortality in older adults who have intensive procedures before VAD placement, coupled with the unlikelihood of cardiac transplantation, is an important distinction and

deserves recognition by clinicians and discussion with patients (Video 1).

The dichotomization of age in epidemiologic studies has the potential to bias analysis and requires ample clinical justification.²² Although age has been dichotomized in previous studies focusing on VAD placement,^{10,14} we chose to further validate this decision. Using linear regression, we showed an exponential increase of in-hospital mortality after VAD placement in individuals older than the age of 65 years. Clinically, the age of 65 years represents the time point at which the rate of cardiac transplantation begins to decline. Although in younger patients high-risk VAD placement might be attempted to bridge the patient to cardiac transplantation, in older patients transplantation is unlikely and VADs must often be considered destination therapy.

FIGURE 2. In-hospital mortality for patients who received intensive treatments before ventricular assist device placement. Examined treatments included intra-aortic balloon pump (*IABP*), cardiac surgery, mechanical ventilation >96 hours, extracorporeal membrane oxygenation (*ECMO*), and hemodialysis.

TABLE 3. Multivariate analysis of in-hospital mortality after the VAD procedure and sensitivity analysis using age as a continuous variable

	Age dichotomized	Age as a continuous variable
Age > 65 years	1.77 (1.29-2.40)	—
Female sex	1.27 (0.96-1.67)	1.30 (0.99-1.17)
Race		
White	Reference	Reference
Black	1.02 (0.73-1.43)	1.09 (0.79-1.52)
Other*	1.15 (0.80-1.65)	1.17 (0.81-1.68)
Unknown	1.41 (0.90-2.20)	1.42 (0.90-2.23)
Primary payer		
Medicare	Reference	Reference
Medicaid	0.98 (0.63-1.53)	1.12 (0.72-1.72)
Private	0.91 (0.67-1.23)	0.99 (0.75-1.31)
Other†	1.22 (0.68-2.20)	1.33 (0.74-2.38)
Hospital region		
Midwest	Reference	Reference
Northeast	0.97 (0.66-1.43)	0.97 (0.65-1.43)
West	1.06 (0.76-1.49)	1.06 (0.75-1.50)
South	0.84 (0.54-1.32)	0.81 (0.65-1.43)
Household income	1.12 (1.00-1.25)	1.10 (0.99-1.23)
Elective admission	0.75 (0.57-0.98)	0.72 (0.55-0.96)
Year of implantation	0.95 (0.88-1.03)	0.94 (0.87-1.02)
Elixhauser score	1.01 (0.95-1.08)	1.01 (0.95-1.09)
IABP before VAD placement	0.91 (0.69-1.20)	0.92 (0.70-1.22)
High-risk intervention before VAD placement‡	5.52 (4.27-7.13)	5.65 (4.35-7.34)

Because of the nonlinear relationship of age and mortality age and age² were included in the continuous model. The results of mortality as a plot of age against the probability of in-hospital mortality is shown in Figure 1. Data are presented as OR (95% CI). IABP, Intra-aortic balloon pump; VAD, ventricular assist device. *Includes Hispanic, Asian or Pacific Islander, Native American, and other. †Includes self-pay, no charge, and other. ‡Includes vasopressors, intra-aortic balloon pump, extracorporeal membrane oxygenation, hemodialysis, mechanical ventilation, and same admission cardiac surgery before VAD placement.

Previous studies have shown similar short-term mortality between younger and older VAD recipients. The Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) report showed 30-day survival of 93% for VAD patients aged 70 years or older.⁸ Likewise, a single-center study reported by Adamson and colleagues⁶ showed a 30-day survival of 97% for patients older than 70 years.⁶ In our study 17.2% of patients aged older than 65 years died in the hospital after VAD implantation. The discrepancy in short-term mortality might in part be explained by differences in measurement. A subset of patients captured in the NIS died >30 days after VAD implantation, but while still in-hospital. The high mortality identified in our study could also stem from differences in cohort selection and study periods. INTERMACS collects data from sites approved by the registry, which currently includes 127 centers. In our study, a cohort was extracted on the basis of a weighted sample of hospitals participating in the NIS, which in 2011 included approximately 1000 centers and is the single largest all-payer publicly available database in the United States. The inclusion of hospitals outside of INTERMACS helps explain the higher overall number of VAD placements seen in this

study compared with recent reports using the INTERMACS registry. The INTERMACS registry reports a 1-year mortality rate of 20% in patients after LVAD implantation. Other multi-institutional studies have shown a 1-year mortality of 25% in patients aged 70 years and older compared with 16% in patients aged 60-69 years.¹⁰ Both are higher than the in-hospital mortality reported in this study, but compare well if our data are projected out.

The number of patients older than age 65 years with heart failure is expected to increase to 3.9 million by the year 2030. However, the availability of donor hearts remains stable; thus, we expect the utilization of VADs to increase.^{23,24} Although VADs offer a more readily available method of cardiovascular support than heart transplantation, they are associated with significant morbidity, caregiver burden, and complicated end of life care.^{12,25-27} These challenges place further importance on optimizing patient selection and the shared decision-making process before VAD implantation.

The decision to proceed with VAD placement remains a difficult challenge for clinicians. In particular, compared with heart transplantation, the criteria for VAD patient selection are less well defined.^{28,29} Several risk-assessment

FIGURE 3. Ventricular assist device implantation and in-hospital mortality between 2010 and 2014 for those aged 18-65 years and those older than 65 years.

tools use clinical and laboratory variables to predict postoperative complications, mortality, and functional outcome.³⁰⁻³³ Increasingly, measures of frailty are used as a predictor for heightened risk of adverse outcomes.³⁴⁻³⁶ Our study further suggests that the intensity of the

immediate medical care should be included in the risk assessment of VAD surgery. Not surprisingly, intensive procedures such as cardiac surgery, ECMO, mechanical ventilation, or hemodialysis before VAD implantation were associated with high in-hospital mortality. This is true for older and younger patients, yet the increase is substantially higher in patients older than the age of 65 years. In our study, we found that nearly 50% of older patients who had 1 or more intensive procedures before VAD placement died in the hospital. In contrast, IABP had only a minor effect on in-hospital mortality in younger patients and in patients older than 65 years of age it had no significant effect on in-hospital mortality.

Finally, equitable access to this treatment remains a concern.³⁷ Older VAD recipients were overwhelmingly white and male. Historical evidence shows decreased access to evidence-based treatment for women and minority patients.^{38,39} Further analysis on access will enable us to address potential disparities and cost considerations as VAD becomes more common.

Limitation

The findings of this study should be interpreted within the limitations of study design. First, clinical data such as INTERMACS profile, laboratory data, medications, and echocardiography data were not available, limiting our ability to study granular clinical characteristics. The data represent a cross-sectional assessment of device implantation; longitudinal clinical outcomes might offer a more comprehensive understanding of differences in clinical outcomes between patients ages 18-65 years versus patients older than 65 years. For example, we are unable to determine readmission rates or long-term complications such as pump thrombosis. In our analysis, we used sample weights that are projected from NIS collected data. This method is

FIGURE 4. Distribution of ventricular assist device (VAD) placement and heart transplantation stratified according to age. After the age of 70 years the opportunity for heart transplantation is exceptionally rare.

VIDEO 1. The second author (Brooks Udelsman, MD) presenting a short summary of the study, highlighting the central findings and conclusions. Video available at: [https://www.jtcvs.org/article/S0022-5223\(18\)32962-3/fulltext](https://www.jtcvs.org/article/S0022-5223(18)32962-3/fulltext).

designed to help study relatively rare events, such as VAD placement, and to identify national trends. This method has been validated several times, including in the study of VAD and congestive heart disease.^{13,17,18}

Although most VADs are left-sided, it is not possible to identify the number of right VADs implanted in this study. On the basis of INTERMACS data from this time period there were only 116 right-sided VADs placed between 2006 and 2014.⁸ Although it is unlikely that all of these right VADs were implanted during our study period of 2010–2014, if they were they would only represent 0.8% of the study population. It is also not possible to identify the type or model of VAD device implanted. Furthermore, NIS data do not distinguish between VADs that were used for destination therapy versus bridge to transplantation because there are no administrative codes for that distinction.

We analyzed the frequency of heart transplantations in the NIS database and determined that only 229 patients older than 70 years received a heart transplantation between 2010 and 2014; thus, most VADs for patients older than 70 years were for destination therapy. We chose to investigate outcomes of patients between the years of 2010 and 2014, because this represents a period of relatively stability in administrative coding and allowed for more robust analysis. However, the field advances rapidly. Although data in this study are recent, it is possible they do not perfectly reflect contemporary trends. Finally, we are limited in ascertainment of true cost of hospital care accrued during the index admission; our study only used hospital charges as a proxy measure.

CONCLUSIONS

In this nationally representative cohort, older patients who underwent major procedures during the hospitalization before VAD implantation had high in-hospital mortality (48.2%) and a low likelihood of cardiac transplantation. Future efforts to improve patient selection might help better align destination VAD implantation with those most likely to benefit.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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TABLE E1. In-hospital intensive procedures and treatments

Description	ICD-9 code
Intra-aortic balloon pump	37.61
Mechanical ventilation	96.70, 96.71, 96.72
Hemodialysis	39.95
ECMO	37.62
Invasive mechanical ventilation ≥ 96 hours	96.72
Cardiac surgery	
Operations on valves and septa of heart	
Closed heart valvotomy, unspecified valve	35
Closed heart valvotomy, aortic valve	35.01
Closed heart valvotomy, mitral valve	35.02
Closed heart valvotomy, pulmonary valve	35.03
Closed heart valvotomy, tricuspid valve	35.04
Endovascular replacement of aortic valve	35.05
Transapical replacement of aortic valve	35.06
Endovascular replacement of pulmonary valve	35.07
Transapical replacement of pulmonary valve	35.08
Endovascular replacement of unspecified heart valve	35.09
Open heart valvuloplasty without replacement, unspecified valve	35.1
Open heart valvuloplasty of aortic valve without replacement	35.11
Open heart valvuloplasty of mitral valve without replacement	35.12
Open heart valvuloplasty of pulmonary valve without replacement	35.13
Open heart valvuloplasty of tricuspid valve without replacement	35.14
Open and other replacement of unspecified heart valve	35.2
Open and other replacement of aortic valve with tissue graft	35.21
Open and other replacement of aortic valve	35.22
Open and other replacement of mitral valve with tissue graft	35.23
Open and other replacement of mitral valve	35.24
Open and other replacement of pulmonary valve with tissue graft	35.25
Open and other replacement of pulmonary valve	35.26
Open and other replacement of tricuspid valve with tissue graft	35.27
Open and other replacement of tricuspid valve	35.28
Operations on papillary muscle	35.31
Operations on chordae tendineae	35.32
Annuloplasty	35.33
Infundibulectomy	35.34
Operations on trabeculae carneae cordis	35.35
Operations on other structures adjacent to valves of heart	35.39
Enlargement of existing atrial septal defect	35.41
Creation of septal defect in heart	35.42
Repair of unspecified septal defect of heart with prosthesis	35.5
Repair of atrial septal defect with prosthesis, open technique	35.51
Repair of atrial septal defect with prosthesis, closed technique	35.52
Repair of ventricular septal defect with prosthesis, open technique	35.53
Repair of endocardial cushion defect with prosthesis	35.54
Repair of ventricular septal defect with prosthesis, closed technique	35.55
Repair of unspecified septal defect of heart with tissue graft	35.6
Repair of atrial septal defect with tissue graft	35.61
Repair of ventricular septal defect with tissue graft	35.62
Repair of endocardial cushion defect with tissue graft	35.63
Other and unspecified repair of unspecified septal defect of heart	35.7
Other and unspecified repair of atrial septal defect	35.71
Other and unspecified repair of ventricular septal defect	35.72
Other and unspecified repair of endocardial cushion defect	35.73

(Continued)

TABLE E1. Continued

Description	ICD-9 code
Total repair of tetralogy of Fallot	35.81
Total repair of total anomalous pulmonary venous connection	35.82
Total repair of truncus arteriosus	35.83
Total correction of transposition of great vessels, not elsewhere classified	35.84
Interatrial transposition of venous return	35.91
Creation of conduit between right ventricle and pulmonary artery	35.92
Creation of conduit between left ventricle and aorta	35.93
Creation of conduit between atrium and pulmonary artery	35.94
Revision of corrective procedure on heart	35.95
Percutaneous balloon valvuloplasty	35.96
Percutaneous mitral valve repair with implant	35.97
Other operations on septa of heart	35.98
Other operations on valves of heart	35.99
Operations on vessels of heart	
Open chest coronary artery angioplasty	36.03
Intracoronary artery thrombolytic infusion	36.04
Insertion of non-drug-eluting coronary artery stent(s)	36.06
Insertion of drug-eluting coronary artery stent(s)	36.07
Other removal of coronary artery obstruction	36.09
Aortocoronary bypass for heart revascularization, not otherwise specified	36.1
(Aorto)coronary bypass of 1 coronary artery	36.11
(Aorto)coronary bypass of 2 coronary arteries	36.12
(Aorto)coronary bypass of 3 coronary arteries	36.13
(Aorto)coronary bypass of 4 or more coronary arteries	36.14
Single internal mammary-coronary artery bypass	36.15
Double internal mammary-coronary artery bypass	36.16
Abdominal-coronary artery bypass	36.17
Other bypass anastomosis for heart revascularization	36.19
Heart revascularization by arterial implant	36.2
Open chest transmyocardial revascularization	36.31
Other transmyocardial revascularization	36.32
Endoscopic transmyocardial revascularization	36.33
Percutaneous transmyocardial revascularization	36.34
Other heart revascularization	36.39
Repair of aneurysm of coronary vessel	36.91
Other operations on vessels of heart	36.99
Cardiotomy and pericardiotomy	
Incision of heart, not otherwise specified	37.1
Cardiotomy	37.11
Pericardiotomy	37.12
Pericardiectomy and excision of lesion of heart	
Pericardiectomy	37.31
Excision of aneurysm of heart	37.32
Excision or destruction of other lesion or tissue of heart, open approach	37.33
Excision or destruction of other lesion or tissue of heart, endovascular approach	37.34
Partial ventriculectomy	37.35
Excision, destruction, or exclusion of left atrial appendage	37.36
Excision or destruction of other lesion or tissue of heart, thoracoscopic approach	37.37
Major aortic dissection or aneurysm repair	
Unspecified site	441
Ascending aorta	441.01
Thoracoabdominal	441.03
Ascending aorta aneurysm, ruptured	441.1
Ascending aorta aneurysm without mention of rupture	441.2
Thoracoabdominal aneurysm, ruptured	441.6

(Continued)

TABLE E1. Continued

Description	ICD-9 code
Thoracoabdominal aneurysm, without mention of rupture	441.7
Aortic aneurysm of unspecified site without mention of rupture	441.9

ICD-9, International Classification of Diseases, Ninth Revision; ECMO, extracorporeal membrane oxygenation.

TABLE E2. Individual components of Elixhauser comorbidity index

	Overall (n = 15,021 ± 1055)		Ages 18-65 years (n = 10,790 ± 782)		Age older than 65 years (n = 4231 ± 329)		P value
	n (%)	SE	n	SE	n	SE	
Congestive heart failure*	85 (0.6)	39	71 (0.7)	35	14 (0.3)	8	.24
Valvular disease*	30 (0.2)	16	25 (0.2)	15	5 (0.1)	5	.54
Pulmonary circulation disorders	44 (0.3)	21	39 (0.4)	21	5 (0.1)	5	.29
Peripheral vascular disorders	1325 (8.8)	121	793 (7.4)	90	532 (12.6)	61	<.001
Hypertension	6628 (44.1)	518	4568 (42.3)	375	2060 (48.7)	179	.03
Paralysis	359 (2.4)	47	264 (2.5)	40	94 (2.2)	21	.71
Other neurologic disorders	783 (5.2)	90	521 (4.8)	69	261 (6.2)	39	.12
Chronic pulmonary disease	2715 (18.1)	241	1817 (16.8)	178	898 (21.2)	98	.02
Diabetes, uncomplicated	3928 (26.1)	301	2739 (25.4)	225	1188 (28.1)	111	.15
Diabetes, complicated	1085 (7.2)	102	722 (6.7)	79	363 (8.6)	47	.08
Hypothyroidism	1744 (11.6)	145	1108 (10.2)	106	636 (15.0)	68	<.001
Chronic kidney disease	5989 (39.9)	481	3905 (36.1)	330	2084 (49.2)	189	<.001
Liver disease	533 (3.5)	62	406 (3.8)	52	127 (3.0)	27	.31
Peptic ulcer disease, excluding bleeding	5 (0.03)	5	5 (0.04)	5	0 (0)	0	1
Acquired immune deficiency syndrome	20 (0.13)	10	20 (0.19)	10	0 (0)	0	1
Lymphoma	167 (1.1)	34	109 (1.0)	26	58 (1.4)	20	.4
Metastatic cancer	35 (0.2)	13	20 (0.18)	10	15 (0.4)	9	.37
Solid tumor without metastasis	140 (0.9)	31	85 (0.8)	22	55 (1.3)	19	.22
Rheumatoid arthritis/collagen vascular diseases	178 (1.2)	32	114 (1.1)	25	64 (1.5)	18	.29
Coagulopathy	5778 (38.5)	482	4010 (37.2)	360	1768 (41.8)	152	.02
Obesity	2431 (16.2)	187	2058 (19.1)	167	373 (8.8)	51	<.001
Weight loss	4102 (27.3)	346	2721 (25.2)	250	1381 (32.6)	130	.002
Fluid and electrolyte disorders	9778 (65.1)	759	7192 (66.7)	577	2586 (61.1)	215	.007
Blood loss anemia	255 (1.7)	44	172 (1.6)	35	83 (2.0)	22	.49
Deficiency anemias	3169 (21.3)	315	2310 (21.4)	242	886 (20.9)	96	.76
Alcohol use	385 (2.6)	50	336 (3.1)	45	49 (1.1)	17	.003
Drug abuse	330 (2.2)	49	321 (3.0)	48	9 (0.2)	7	<.001
Psychoses	483 (3.2)	66	389 (3.6)	61	94 (2.2)	23	.08
Depression	1639 (10.9)	153	1233 (11.4)	119	406 (9.6)	57	.14

SE, Standard error of the mean. *Note that the diagnosis of congestive heart failure and valvular heart disease are primary diagnoses for a large percentage of patients in this study and thus not readily captured by our Elixhauser comorbidity index. Because of the ubiquity of these diagnoses in the study population they are essentially dropped in this analysis.

TABLE E3. Univariate analysis for in-hospital mortality after the VAD procedure

	OR (95% CI)	P value
Age older than 65 years	1.02 (1.01-1.04)	<.001
Female sex	1.22 (0.94-1.59)	.14
Race		
White	Reference	–
Black	0.77 (0.58-1.03)	.08
Other*	1.19 (0.86-1.64)	.29
Unknown	1.40 (0.96-2.06)	.08
Primary payer		
Medicare	Reference	–
Medicaid	0.89 (0.63-1.72)	.52
Private	0.99 (0.75-1.31)	.34
Other†	1.33 (0.74-2.38)	.47
Hospital region		
Midwest	Reference	
Northeast	1.00 (0.72-1.40)	.99
West	0.88 (0.64-1.21)	.41
South	0.82 (0.53-1.26)	.37
Household income	1.16 (1.05-1.27)	.003
Elective admission	0.65 (0.50-0.85)	.002
Year of implantation	0.96 (0.88-1.05)	.35
Elixhauser score	1.02 (0.95-1.07)	.72
IABP before VAD placement	1.29 (1.00-1.66)	.05
High-risk intervention before VAD placement‡	5.50 (4.38-6.91)	<.001

Age × Age was used in addition to Age as a continuous variable because of the nonlinear relationship of age and mortality. OR, Odds ratio; CI, confidence interval; IABP, intra-aortic balloon pump; VAD, ventricular assist device. *Includes Hispanic, Asian or Pacific Islander, Native American, and other. †Includes self-pay, no charge, and other. ‡Includes vasopressors, IABP, extracorporeal membrane oxygenation, hemodialysis, mechanical ventilation, and same admission cardiac surgery before VAD placement.