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Association of Cardiac Rehabilitation with Hospitalizations and Mortality after Ventricular Assist Device Implantation

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Structured Abstract

Objectives—This study characterized cardiac rehabilitation (CR) utilization amongst ventricular assist device (VAD) recipients in the United States and the association of CR with one-year hospitalizations and mortality using the 2013–2015 Medicare files.

Background—Exercise-based CR is indicated in patients with heart failure with reduced ejection fraction, but there are no data regarding CR participation after VAD implantation.

Methods—The study included Medicare beneficiaries enrolled due to disability or age ≥65. We identified VAD patients by diagnosis codes and cumulated CR sessions occurring within one year after VAD implantation. We used multivariable-adjusted Andersen-Gill models to evaluate the association of CR with one-year hospitalization risk and Cox regression to evaluate the association of CR with one-year mortality.

Results—There were 1164 VADs implanted in Medicare beneficiaries in the United States in 2014. CR utilization was low, with 348 patients (30%) participating in CR programs. The Midwest had the highest proportion of VAD patients initiating CR (38%) while the Northeast had the lowest

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proportion of CR participants (25%). Each 5-year increase in age was associated with attending an additional 1.6 CR sessions (95% confidence interval (CI) 0.7–2.5, $p<0.001$). CR participation was associated with a 23% lower one-year hospitalization risk (95% CI 11%–33%, $p<0.001$) and a 47% lower one-year mortality risk (95% CI 18%–66%, $p<0.01$) after multivariable adjustment.

Conclusions—Approximately one third of VAD recipients attend CR. Though it is not possible to fully account for unmeasured confounding, VAD patients who participate in CR appear to have lower risk for hospitalization and mortality.

Keywords

Cardiac rehabilitation; ventricular assist device; hospitalizations; readmissions; mortality

Introduction

Cardiac rehabilitation (CR), a systematic, multidisciplinary program of prescribed exercise, nutritional counseling, psychosocial support, and cardiovascular risk factor control, is indicated in patients with stable heart failure with reduced ejection fraction (HFrEF) as well as after heart transplantation(1). CR decreases mortality and improves quality of life in patients with ischemic heart disease(2). Despite its known benefits, less than 20% of eligible patients participate in CR programs(3–7). To date, there are no data on CR participation after ventricular assist device (VAD) implantation.

Exercise training in VAD patients is feasible and safe, and improves self-reported health status, peak oxygen uptake and skeletal muscle function(8–11). Moreover, exercise capacity is significantly diminished after VAD implantation, increasing the relative benefit of improvements in exercise tolerance(12). VAD implantation is not currently one of the indications for CR covered by Medicare. However, many VAD patients are eligible for CR under the HFrEF indication, which covers patients with stable, chronic heart failure and a left ventricular ejection fraction (LVEF) of ≤35%(5). The Centers for Medicare & Medicaid Services (CMS) define stable chronic heart failure patients as those that have not had cardiovascular hospitalizations within the prior 6 weeks(13). Almost all patients who are candidates for VAD implantation meet medical criteria for disability benefits (LVEF ≤30% with symptoms impacting activities of daily living) and are thus eligible for Medicare(14).

Using CMS data, we evaluated CR utilization after VAD implantation in the United States. We also characterized the association of CR with one-year hospitalizations and mortality amongst VAD recipients. We hypothesized that CR is associated with a decreased risk of hospitalization and mortality in these patients.

Methods

Data source

We obtained data regarding CR utilization in VAD recipients in the United States from the 2014–2015 Medicare 100% Limited Data Set (LDS) files from CMS. These files contain all inpatient and institutional outpatient claims for fee-for-service Medicare beneficiaries. The institutional review board of Vanderbilt University Medical Center approved the study, which was carried out under the auspices of a data use agreement with CMS.

Patient population

The study population included Medicare beneficiaries enrolled in 2014 due to disability or age ≥65 who resided in the United States, had uninterrupted fee-for-service coverage until their death or for one year following discharge and did not attend any CR sessions in the year prior to VAD implantation. Inclusion in the study was based on a discharge diagnosis code (International Classification of Diseases 9th Revision (ICD-9) codes 37.60, 37.63, 37.65, 37.66) or procedure code (Current Procedure Terminology (CPT) codes 33975, 33976, 33979, 33981, 33982, 33983 0051T, 0052T, 0053T) for VAD implantation, replacement or repair.

Outcomes

Participation in CR programs, defined as a binary variable (yes/no), was the primary outcome. We searched the Medicare outpatient LDS files for CR claims (CPT codes 93797, 93798, G0422, G0423, or S9472) occurring within one year after the VAD hospitalization discharge date. Secondary outcomes included (1) CR as a continuous variable (number of sessions attended); (2) the number of hospitalizations that occurred in the one-year period after patients underwent VAD implantation, determined from the Inpatient file; and (3) all-cause mortality, determined from death dates in the Medicare denominator file.

Other variables

Patients receiving heart transplants within one year of discharge from the VAD hospitalization were identified by CPT code 33945 or ICD-9 code 37.51. We obtained demographic characteristics, including age, sex, race (Black, White, or Other) and geographic census division (Midwest, Northeast, West and South) from the denominator file. We characterized the burden of comorbidities with Elixhauser comorbidity groups present during the hospitalization for VAD implantation and the preceding 12 months using ICD-9 codes as described previously(15). We determined whether the VAD hospital had a CR program from the American Hospital Association Annual Survey of Hospitals(16). We characterized socioeconomic status with median income from the patient’s county of residence, obtained from the United States Census Bureau Small Area Income and Poverty Estimates for 2014(17).

Statistical analysis

Baseline demographic and geographic characteristics of VAD recipients participating in CR were compared to those who did not participate in CR programs using chi-square tests for categorical variables and Wilcoxon rank-sum tests for continuous variables. We used multivariable-adjusted logistic regression to evaluate the effect of individual covariates on CR initiation rates. We used linear regression to analyze predictors of the number of CR sessions attended. The Andersen-Gill model with a robust sandwich covariance estimator (also known as a proportional means model), a technique for the analysis of repeated events, was used to model the effect of participating in CR on one-year hospitalization risk after adjusting for covariates(18,19). Patients receiving heart transplants were censored at the time of the transplant admission. CR participation was used as a time-updated covariate such that all individuals in the sample were considered non-CR participants at baseline and remained so until beginning CR. For example, if an individual had no hospitalizations in the year following VAD implantation and did not initiate CR until 3 months after discharge, he or she would contribute 3 months of non-hospitalization time in the non-CR participant group and the remaining 9 months in the follow-up period would contribute to the CR participant group. This approach, known as the Mantel-Byar method, was chosen to minimize immortal person-time bias(20,21). The Mantel-Byar method has been shown to yield unbiased estimates even when event hazards change over time(20).

To evaluate the association of CR with one-year mortality risk, we constructed a Cox regression model adjusting for clinical characteristics and comorbidities and again used CR participation as a time-varying covariate in order to minimize immortal person-time bias. As a sensitivity analysis to address potential healthy cohort bias, we created a marginal structural model with inverse probability of treatment weighting(22). For the marginal structural model, the follow-up period was broken into one-week blocks starting at 3-weeks post discharge in order to accumulate enough CR participants, and the sample was reweighted at the beginning of each one-week interval. This weighting scheme allowed us to estimate the average treatment effect in the CR participants. Thus, the CR participants at each time point served as our reference population to which the sample was standardized.

We conducted an additional analysis to measure the sensitivity of the effect of CR on mortality to residual confounding from unmeasured variables, specifically frailty, after adjusting for observed confounders. This method makes statistical inferences about the true exposure effect of CR by specifying distributions of unmeasured confounders in CR participants and nonparticipants along with the effects of these confounders on the outcome, i.e. mortality(23). Frailty, defined as a score of >0.25 on the Rockwood Frailty Index(24), was found in a study of 99 VAD patients to have a prevalence of 61.6% prior to VAD implantation and a hazard ratio (HR) of 2.31 (95% confidence interval (CI) 1.18 to 4.98, $p<0.05$) for one-year mortality(25). These point estimates were used as the basis for the sensitivity analysis.

All analyses used SAS version 9.4(26) and R version 3.1.2(27).

Results

Cohort derivation

There was a total of 1647 Medicare beneficiaries receiving VADs in 2014. We excluded 95 patients who attended CR in the year prior to hospital admission for VAD implantation, 179 patients who did not have uninterrupted fee-for-service Medicare coverage, and 209 patients who died in the hospital or on the day of discharge for a final sample size of 1164 VAD recipients.

Cohort characteristics

A total of 348 (30%) of Medicare beneficiaries receiving VADs initiated CR (Table 1). The average age of the cohort was 61 and 20% of VAD recipients were female. Most patients undergoing VAD implantation were White (72%), while 23% were Black and 5% were in another racial category, including Asian and non-White Hispanics. Almost all patients in the study (96%) received VADs at hospitals that reported having CR programs. A total of 69 patients (6%) underwent heart transplantation within one year of VAD implantation, with a greater proportion receiving transplants amongst CR participants as compared to nonparticipants (8% vs 5%, $p<0.05$). One-year mortality was 22% amongst CR nonparticipants (179 deaths) compared to 7% amongst CR participants (25 deaths, $p<0.0001$). After VAD implantation, 31% of patients (363) were discharged to inpatient rehabilitation facilities (IRFs) or skilled nursing facilities (SNFs).

Cardiac rehabilitation utilization

The only significant predictor of CR initiation amongst VAD recipients was census region (Table 2). VAD patients in the Midwest had a higher odds of initiating CR than those in the South (OR 1.59, 95% CI 1.16–2.18, $p<0.01$). None of the comorbidities nor age was associated with CR initiation.

Those patients who did initiate CR attended a mean of 24.5 ± standard deviation (SD) 15.0 sessions, fewer than the generally recommended program of 36 sessions (Table 2). Less than one third of CR attendees participated in the full course of 36 sessions. Older patients attended more CR sessions, with a 1.6 session increase (95% CI 0.7–2.5, $p<0.001$) per 5-year increase in age. VAD recipients with renal failure attended an average of 7.3 fewer sessions (95% CI 3.5–11.0, $p<0.001$). There was a small but statistically significant inverse association between length of stay during the VAD hospitalization and the number of CR sessions attended (−.5 sessions per 5-day increase in length of stay, 95% CI −0.9 to −0.1, $p<0.05$). Amongst CR participants, the average time between discharge and the first CR session was 109 ± SD 84 days, with a median of 83 (interquartile range 44–155) days.

Cardiac rehabilitation and hospitalizations

The median number of total hospitalizations within one year of VAD implantation in the cohort was 2 (interquartile range 1–3), with 914 patients (79%) hospitalized at least once during this time. After multivariable adjustment, participation in a CR program was associated with a 23% (95% CI 11%–33%, $p<0.001$) decrease in one-year hospitalizations (Table 3). Multivariable-adjusted cumulative hospitalizations over one year, stratified by CR participation, are displayed in the Figure. Patients with chronic pulmonary disease prior to VAD implantation were more likely to be readmitted (HR 1.42, 95% CI 1.20–1.68, $p<0.0001$), as were those with renal failure (HR 1.28, 95% CI 1.13–1.45, $p<0.001$). Patients discharged to a IRF or SNF were also more likely to be readmitted (HR 1.15, 95% CI 1.02–1.29, $p<0.05$). In contrast, patients with a prior history of pulmonary circulation disorders (including pulmonary hypertension) had a lower odds of being readmitted.

Cardiac rehabilitation and mortality

After adjusting for demographics, clinical factors and comorbidities, CR was associated with a decreased risk of mortality in the year after VAD implantation (Table 4, HR 0.53, 95% CI 0.34–0.82, p<0.01). Factors associated with increased one-year mortality included age (HR 1.09 per 5-year increase, 95% CI 1.01–1.19, p<0.05), discharge to an IRF or SNF (HR 1.57, 95% CI 1.17–2.10, p<0.01), peripheral vascular disease (HR 1.45, 95% CI 1.04–2.02, p<0.05), and weight loss (HR 1.42, 95% CI 1.05–1.90, p<0.05). A sensitivity analysis using a marginal structural model demonstrated a similar association between CR and one-year mortality (HR 0.47, 95% CI 0.30–0.74, p=0.001). Plots of standardized mean differences for individual covariates after using inverse probability of treatment weighting are displayed in Supplementary Figures 1–2, demonstrating that the sample was well-balanced on covariates at 1 and 12 months post-discharge.

An additional analysis was conducted to measure the sensitivity of the effect of CR on mortality to residual confounding from unmeasured variables(23), specifically frailty. Assuming frailty has an HR of 2.31 for one-year mortality and a prevalence of 61.6% in the VAD population based on prior work(25), CR participants would need to have a frailty prevalence of 36.8% or less to make the observed effect of CR on one-year mortality nonsignificant (i.e. a frailty prevalence of 36.8% would make the effect of CR nonsignificant exactly at p=0.05).

Discussion

This is the first study to report CR utilization rates in patients undergoing VAD implantation in the United States. Approximately one third of VAD patients participated in CR programs. There was geographic variation in CR after VAD implantation, with the Midwest having the highest CR initiation rates. VAD patients participating in CR programs began an average of three months after discharge and attended two thirds of the recommended course of 36 sessions. Younger CR participants attended significantly fewer CR sessions than older patients. Although it is not possible to fully account for all confounding variables, VAD patients who participate in CR appear to have lower risk for hospitalization and all-cause death.

Cardiac rehabilitation by indication

CR utilization varies by indication, with reported initiation rates ranging from less than 10% in patients with systolic heart failure(5), to 10–20% in patients with acute myocardial infarction (AMI) and percutaneous coronary intervention(6,28), and up to 50% in patients receiving heart transplants(29). Approximately one third of patients undergoing coronary artery bypass grafting (3,4,7,30) participate in CR programs, a proportion similar to that seen in VAD patients in the current study. Unlike the aforementioned indications, Medicare does not specifically cover CR after VAD implantation and these patients are often referred to CR programs under the auspices of other conditions. VAD patients could potentially be eligible for CR Medicare coverage under the HFrEF indication(13), stable angina pectoris(1) (which covers most patients with ischemic heart disease), and/or AMI(1) (which covers patients experiencing an AMI within the prior year). *Cardiac rehabilitation initiation* The only significant predictor of CR initiation amongst VAD recipients was census region. The Midwest census region had a significantly higher proportion of VAD patients initiating CR than the other regions. This geographic variation in CR utilization is consistent with prior studies of CR use after acute myocardial infarction and coronary artery bypass grafting(7). The fact that geographic location is more strongly associated with the odds of initiating CR than any of the clinical characteristics or comorbidities in this population underscores the importance of further research to characterize variation in CR referral patterns and access. For those initiating CR, the time between discharge and the first CR appointment was much longer in VAD patients (median 83 days) as compared to a recent study in patients with ischemic heart disease (median 42 days)(31). This delay is likely attributable to the significant postoperative recovery period after VAD implantation as well as the Medicare requirement that patients referred to CR programs for systolic heart failure be stable for 6 weeks (e.g. no cardiovascular hospitalizations) prior to attending the first session(13).

Cardiac rehabilitation dose

A dose-dependent relationship has been identified between the number of sessions attended and mortality in patients with ischemic heart disease(3,4). Interestingly, older CR participants were more likely to attend more sessions than younger participants. One might expect that older VAD recipients would be inclined to participate in fewer CR sessions due to a higher burden of comorbidities and frailty(24,25). It is possible that younger VAD patients may be more likely to return to work, and work responsibilities are a significant barrier to attending CR programs(32,33). Renal failure was associated with a significant decrease in the number of sessions attended amongst CR participants, but not with the odds of initiating CR. This is likely representative of the fact that the time demands of hemodialysis are a major barrier to attending CR sessions three times weekly.

Cardiac rehabilitation and one-year outcomes after VAD implantation

CR was associated with fewer hospitalizations in the year following VAD implantation. The magnitude of this association in our analyses (a 23% decrease, 95% CI 0.67–0.89) is similar to that in other studies(19). A recent meta-analysis of the effect of exercise-based CR versus usual care on hospitalizations demonstrated an 18% decrease in hospitalization risk (95% CI 4%–30%)(2). The etiology of this association is likely multifactorial. Beyond CR's known beneficial effects on skeletal muscle function, peak oxygen uptake and health status in VAD recipients (8–10), CR offers an opportunity for healthcare professionals to serially monitor these patients, potentially averting unplanned hospitalizations.

In our adjusted analyses COPD and renal failure were the only comorbidities that were associated with an increased hospitalization risk in VAD patients. Curiously, pulmonary circulation disorders (including pulmonary hypertension) prior to VAD implantation were associated with a decreased risk of hospitalization. It is possible that such patients experience disproportionate benefit from a VAD as these devices significantly improve pulmonary arterial pressures(34), though this conclusion would be speculative with the available data and warrants further study.

The magnitude of the association between CR and one-year mortality risk (HR=0.53, 95% CI 0.32–0.76) is similar to that in prior studies as well. Suaya et al. identified a 56% reduction in one-year mortality risk in an analysis of over 600,000 Medicare beneficiaries hospitalized for acute myocardial infarction or CABG(4). Another study demonstrated a 46% reduction in all-cause mortality in a cohort of 846 CABG patients(30).

Sensitivity analyses

It is important to interpret all of these results in the context of potential confounding due to healthy cohort bias, which could overestimate of the effect of CR on mortality as well as hospitalizations. However, our analysis controlled extensively for sociodemographic and clinical factors, and Elixhauser comorbidity groups provide effective comorbidity adjustment in surgical populations(15), including heart transplant patients(35) and those receiving VADs(36). We also used multiple statistical techniques, including marginal structural models, to control for observed confounders.

Frailty or functional impairment represents one of the most significant unobserved confounders, as frailty cannot be well-characterized with administrative claims data(24). Using prior work by Dunlay et al.(25), who found that 62% of VAD recipients were frail (as defined by the Rockwood Frailty Index(24)) prior to device implantation, we demonstrated that the prevalence of frailty in CR participants would have to be very low (<37%) for the effect of CR on mortality to become nonsignificant. It is unlikely that frailty would be this infrequent in VAD recipients who participated in CR, as frailty prevalence is 37% after ten years of follow-up in a similarly-aged community cohort of myocardial infarction survivors(37) and is well over 35% in younger intensive care unit populations(38). Given this context the association of CR with one-year mortality appears to be quite robust, even the setting of unobserved confounding.

Clinical and policy implications

VAD patients necessitate multidisciplinary care and require an enormous amount of resources. Our results suggest that CR is associated with improved outcomes in this population. Further study is needed on the mechanisms by which VAD patients are being referred to CR (i.e. HFrEF, stable angina pectoris or AMI) and whether the six-week interval after discharge required for a patient to be deemed stable under the HFrEF indication is leading to delays in CR initiation.

Study limitations

Our study has limitations in addition to those previously addressed. First, we were only able to capture utilization data on VAD patients age ≥65 or with Medicare disability benefits. The fact that a significant number of patients in our cohort received disability coverage does not indicate that they were less likely to participate in CR than those eligible by age, as almost all patients receiving VADs would meet the chronic heart failure medical criteria for disability benefits. Second, our data are obtained from CMS administrative claims, which are not adjudicated. However, CMS data have been used to effectively study many cardiovascular therapies, including CR, in prior work(3,4,7). Third, our analyses were limited to VAD patients enrolled in fee-for-service Medicare and may not be generalizable to patients enrolled in Medicare private health plans. However, fee-for-service Medicare still accounted for 71% of Medicare beneficiaries in 2014(39). Lastly, the CMS decision memo approving HFrEF as an indication for CR was issued in February 2014, so it is possible that CR uptake in VAD recipients under the HFrEF indication has increased in the following years.

Conclusions

In summary, less than one third of Medicare beneficiaries receiving VADs participate in CR programs in the United States. Although it is not possible to fully account for all confounding variables, VAD patients who participate in CR appear to have lower risk for hospitalization and mortality. These exploratory results suggest opportunities for further, more definitive studies of the effectiveness of CR in this population, as well as to understand factors that drive patient and caregiver decisions regarding CR participation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations List

CMS	Centers for Medicare & Medicaid Services
CPT	Current Procedure Terminology
CR	Cardiac rehabilitation
HFrEF	Heart failure with reduced ejection fraction
ICD-9	International Classification of Diseases 9th Revision
IRF	Inpatient rehabilitation facility
LDS	Limited Data Set
LVEF	Left ventricular ejection fraction
SNF	Skilled nursing facility
VAD	Ventricular assist device

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Clinical Perspectives

Competency in Medical Knowledge

Cardiac rehabilitation is indicated in patients with stable heart failure with reduced ejection fraction, including those receiving ventricular assist devices. Participation in cardiac rehabilitation programs is associated with decreased one-year hospitalizations and mortality in ventricular assist device patients.

Translational Outlook

Further studies are needed to characterize the barriers to cardiac rehabilitation participation in patients receiving ventricular assist devices, along with quality improvement interventions to increase cardiac rehabilitation uptake in this population.

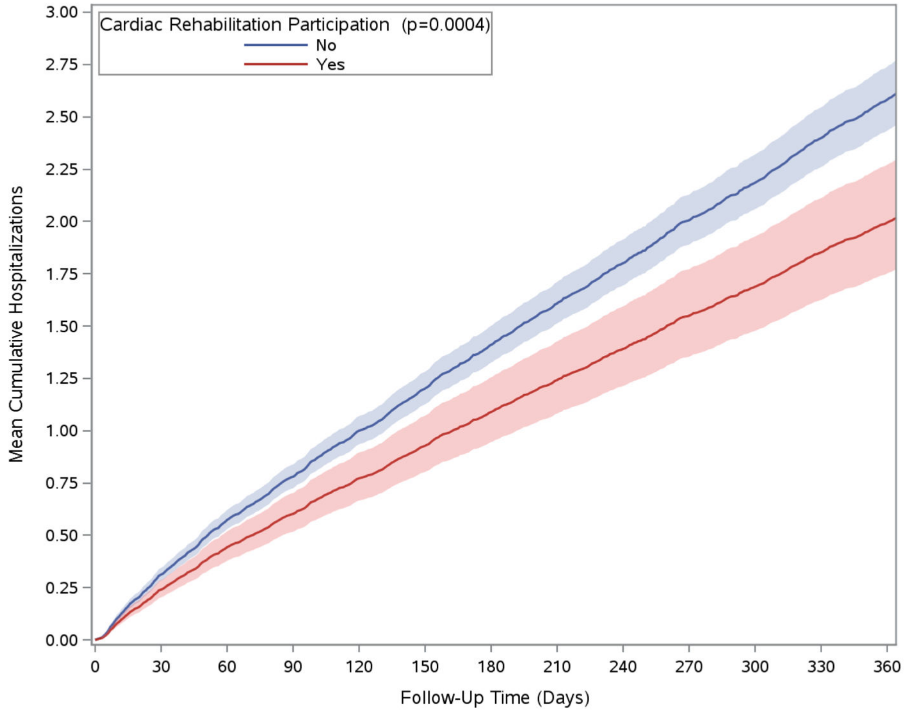

Figure. Cumulative hospitalizations over time for Medicare beneficiaries receiving ventricular assist devices in 2014, stratified by participation in cardiac rehabilitation

Cumulative hospitalizations were calculated using the Andersen-Gill model adjusted for age, sex, race, census region, comorbidities, discharge to an inpatient rehabilitation facility or skilled nursing facility, and length of stay. Shaded areas represent 95% confidence intervals.

Table 1

Baseline characteristics of Medicare beneficiaries receiving ventricular assist devices in 2014 (N=1164).

Characteristic	VADs receiving Medicare	Medicare CR nonparticipants	Medicare CR participants	p-value*
All, n	1164	816 (70%)	348 (30%)	n/a
Demographic				
Age	61.2 ± 11.8	60.7 ± 12.0	62.6 ± 11.2	<0.01
Sex				0.35
Female	237 (20%)	172 (21%)	65 (19%)	--
Male	927 (80%)	644 (79%)	283 (81%)	--
Race				0.10
White	834 (72%)	575 (70%)	259 (74%)	--
Black	265 (23%)	188 (23%)	77 (22%)	--
Other	65 (5%)	53 (7%)	12 (4%)	--
Median county income	$56,477 ±$14,986	$56,077 ± $15,040	$57,416 ± $14,836	0.11
Census Region				<0.01
Midwest	302 (26%)	187 (23%)	115 (33%)	--
Northeast	209 (18%)	157 (19%)	52 (15%)	--
South	514 (44%)	377 (46%)	137 (39%)	--
West	139 (12%)	95 (12%)	44 (13%)	--
Clinical				
CR program at VAD hospital	1117 (96%)	784 (96%)	333 (96%)	0.76
Length of stay (days)	33.8 ± 27.5	35.1 ± 29.7	30.9 ± 21.3	0.10
Discharged to IRF or SNF	363 (31%)	244 (30%)	119 (34%)	0.15
Cormorbidities				
Chronic pulmonary disease	854 (73%)	592 (73%)	262 (75%)	0.33
Depression	349 (30%)	253 (31%)	96 (28%)	0.24
Diabetes	592 (51%)	419 (51%)	173 (50%)	0.61
Hypertension	1019 (88%)	713 (87%)	306 (88%)	0.79
Hypothyroidism	263 (23%)	185 (23%)	78 (22%)	0.92
Liver disease	234 (20%)	170 (21%)	64 (18%)	0.34
Obesity	391 (34%)	267 (33%)	124 (36%)	0.34
Other neurological disorders	154 (13%)	117 (14%)	37 (11%)	0.09
Peripheral vascular disease	212 (18%)	154 (19%)	58 (17%)	0.37
Pulmonary circulation disorders	703 (60%)	479 (59%)	224 (64%)	0.07
Renal failure	790 (68%)	535 (66%)	255 (73%)	<0.01
Weight loss	367 (32%)	255 (31%)	112 (32%)	0.75
VADs receiving transplants within one year	69 (6%)	41 (5%)	28 (8%)	<0.05
One-year hospitalizations	2.3 ± 2.2	2.4 ± 2.2	1.9 ± 2.1	<0.05
One-year mortality	204 (18%)	179 (22%)	25 (7%)	<0.0001

VAD, ventricular assist device; CR, cardiac rehabilitation; IRF, inpatient rehabilitation facility; SNF, skilled nursing facility.

Values are displayed as mean ± standard deviation or n (percentage) unless otherwise noted.

*All p-values obtained by Pearson Chi-Square test or Wilcoxon test.

Table 2

Predictors of cardiac rehabilitation initiation and number of sessions attended amongst Medicare beneficiaries receiving ventricular assist devices in 2014 (N=1164).

Characteristic	Proportion of patients initiating CR, %	Participation in a CR program			CR sessions amongst participants, Mean ± SD	Change in sessions attended*	95% CI	p-value
		Odds Ratio*	95% CI	p-value				
All	30%				24.5 ± 15.0			
Demographic								
Age (5 year increase)	n/a	1.06	0.99, 1.13	0.10	n/a	1.6	0.7, 2.5	<0.001
Sex		--	--	0.45		--	--	0.34
Female	27%	--	Referent	--	24.3 ± 15.5	-2.2	−.5, 2.0	--
Male	31%	1.14	0.81, 1.61	--	25.1 ± 12.7	--	Referent	--
Race		--	--	0.13		--	--	0.96
Black	29%	1.05	0.73, 1.50	--	22.2 ± 13.9	1.2	−.3, 5.8	--
Other	18%	0.52	0.27, 1.003	--	22.4 ± 12.2	1.7	−.1, 10.6	--
White	31%	--	Referent	--	25.3 ± 15.4	--	Referent	--
Median county income (per $10,000 increase)	n/a	1.07	0.97, 1.17	0.17	n/a	0.29	−.8, 1.4	0.57
Census Region		--	--	<0.05		--	--	0.31
Midwest	38%	1.59	1.16, 2.18	--	25.0 ± 13.5	0.7	−.9, 4.4	--
Northeast	25%	0.88	0.59, 1.31	--	27.1 ± 14.4	2.1	−.1, 7.3	--
West	32%	1.18	0.76, 1.82	--	21.8 ± 12.5	−3.4	−8.6, 1.8	--
South	27%	--	Referent	--	24.0 ± 17.1	--	Referent	--
Clinical								
Length of stay (5 day increase)	n/a	0.97	0.94, 1.01	0.10	n/a	−0.5	−0.9, −0.1	<0.05
Discharged to IRF or SNF	33%	1.25	0.93, 1.68	0.15	25.1 ± 13.9	−1.2	−4.7, 2.3	0.41
Comorbidities								
Chronic pulmonary disease	31%	0.92	0.60, 1.40	0.69	24.6 ± 14.7	0.7	−4.7, 6.1	0.86
Depression	28%	0.87	0.65, 1.17	0.35	24.0 ± 14.7	−0.6	−4.1, 3.0	0.75
Diabetes	29%	0.89	0.68, 1.17	0.41	22.6 ± 14.2	−3.2	−6.4, 0.06	<0.05
Hypertension	30%	0.95	0.63, 1.43	0.80	24.6 ± 15.3	3.7	−1.4, 8.7	0.86

Characteristic	Proportion of patients initiating CR, %	Participation in a CR program			CR sessions amongst participants, Mean ± SD	Change in sessions attended*	95% CI	p-value
		Odds Ratio*	95% CI	p-value				
Hypothyroidism	30%	0.95	0.70, 1.30	0.76	24.3 ± 11.7	−1.3	−5.2, 2.6	0.52
Liver disease	27%	0.96	0.69, 1.34	0.81	24.2 ± 15.6	1.8	−2.4, 5.9	0.38
Obesity	32%	1.28	0.95, 1.71	0.10	21.6 ± 14.3	−1.2	−4.9, 2.6	0.48
Other neurological disorders	24%	0.71	0.47, 1.08	0.11	23.6 ± 14.7	−0.2	−5.6, 5.1	0.92
Peripheral vascular disease	27%	0.80	0.56, 1.13	0.20	27.2 ± 15.2	3.5	−0.7, 7.8	0.24
Pulmonary circulation disorders	32%	1.23	0.84, 1.80	0.30	24.6 ± 14.6	0.6	−4.3, 5.5	0.82
Renal failure	32%	1.32	0.98, 1.79	0.07	23.2 ± 14.0	−7.3	−11.0, −3.5	<0.001
Weight loss	31%	1.05	0.78, 1.40	0.75	24.6 ± 13.4	1.2	−2.3, 4.8	0.50

CR, cardiac rehabilitation; CI, confidence interval; IRF, inpatient rehabilitation facility; SNF, skilled nursing facility.

*Adjusted for all listed variables.

Table 3

Predictors of cumulative one-year hospitalization risk amongst Medicare beneficiaries receiving ventricular assist devices in 2014 (N=1164).

	Cumulative one-year hospitalization risk		
Characteristic	**Hazard Ratio***	**95% CI**	**p-value**
CR participation	0.77	0.67, 0.89	<0.001
Demographics			
Age (5 year increase)	0.99	0.96, 1.01	0.31
Sex	--	--	0.76
Male	0.98	0.85, 1.12	--
Female	--	Referent	--
Race	--	--	0.21
Black	1.06	0.92, 1.22	--
Other	0.85	0.68, 1.07	--
White	--	Referent	--
Median county income (per $10,000 increase)	1.01	0.98, 1.05	0.54
Census Region	--	--	0.37
Midwest	1.03	0.90, 1.18	--
Northeast	0.94	0.80, 1.09	--
West	0.88	0.74, 1.05	--
South	--	Referent	--
Clinical			
Length of stay (5 day increase)	1.003	0.995, 1.01	0.50
Discharged to IRF or SNF	1.15	1.02, 1.29	<0.05
Comorbidities			
Chronic pulmonary disease	1.42	1.20, 1.68	<0.0001
Depression	1.14	1.01, 1.28	<0.05
Diabetes	1.11	1.00, 1.24	0.06
Hypertension	1.00	0.84, 1.19	0.99
Hypothyroidism	0.96	0.84, 1.09	0.51
Liver disease	0.95	0.83, 1.09	0.46
Obesity	1.07	0.94, 1.20	0.31
Other neurological disorders	1.05	0.90, 1.23	0.54
Peripheral vascular disease	1.12	0.97, 1.29	0.12
Pulmonary circulation disorders	0.80	0.69, 0.94	<0.01
Renal failure	1.28	1.13, 1.45	<0.001
Weight loss	1.02	0.90, 1.15	0.77

CR, cardiac rehabilitation; CI, confidence interval; IRF, inpatient rehabilitation facility; SNF, skilled nursing facility.

*Hazard ratios derived from the multivariable-adjusted Andersen-Gill model with robust sandwich covariance estimator (or proportional means model) adjusted for all listed covariates. Ventricular assist device recipients receiving transplants were censored at the time of the transplant admission.

Table 4

Predictors of one-year mortality risk amongst Medicare beneficiaries receiving ventricular assist devices in 2014 (N=1164).

	One-year mortality risk		
Characteristic	**Hazard Ratio***	**95% CI**	**p-value**
CR participation	0.53	0.34, 0.82	<0.01
Demographics			
Age (5 year increase)	1.09	1.01, 1.19	<0.05
Sex	--	--	0.69
Male	1.04	0.71, 1.53	--
Female	--	Referent	--
Race	--	--	0.14
Black	0.76	0.50, 1.14	--
Other	1.44	0.82, 2.54	--
White	--	Referent	--
Median county income (per $10,000 increase)	0.93	0.84, 1.04	0.20
Census Region	--	--	0.84
Midwest	0.85	0.59, 1.24	--
Northeast	0.87	0.56, 1.36	--
West	0.97	0.61, 1.64	--
South	--	Referent	--
Clinical			
Length of stay (5 day increase)	1.02	1.00, 1.04	0.07
Discharged to IRF or SNF	1.57	1.17, 2.10	<0.01
Comorbidities			
Chronic pulmonary disease	1.44	0.93, 2.24	0.10
Depression	0.96	0.69, 1.35	0.83
Diabetes	1.23	0.91, 1.67	0.18
Hypertension	1.00	0.63, 1.58	0.98
Hypothyroidism	0.96	0.69, 1.35	0.82
Liver disease	0.94	0.65, 1.34	0.72
Obesity	0.99	0.71, 1.38	0.94
Other neurological disorders	1.30	0.90, 1.89	0.17
Peripheral vascular disease	1.45	1.04, 2.02	<0.05
Pulmonary circulation disorders	0.91	0.63, 1.32	0.62
Renal failure	1.06	0.76, 1.49	0.72
Weight loss	1.42	1.05, 1.90	<0.05

CR, cardiac rehabilitation; CI, confidence interval; IRF, inpatient rehabilitation facility; SNF, skilled nursing facility; VAD, ventricular assist device.

*Hazard ratios derived from a Cox regression model adjusted for all listed covariates.

Ventricular assist device recipients receiving transplants were censored at the time of the transplant admission.

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