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Association of Cardiac Rehabilitation With Decreased Hospitalization and Mortality Risk After Cardiac Valve Surgery

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IMPORTANCE National guidelines recommend cardiac rehabilitation (CR) after cardiac valve surgery, and CR is covered by Medicare for this indication. However, few data exist regarding current CR enrollment after valve surgery.

OBJECTIVE To characterize CR enrollment after cardiac valve surgery and its association with outcomes, including hospitalizations and mortality.

DESIGN, SETTING, AND PARTICIPANTS This cohort study of patients undergoing valve surgery was conducted in calendar year 2014, with follow-up through 2015. The study included all fee-for-service Medicare beneficiaries undergoing open cardiac valve surgery in 2014. Patients identified by inpatient diagnosis codes for open aortic, mitral, tricuspid, and pulmonary valve surgery were included. Data analysis occurred from January 2018 to March 2019.

EXPOSURES Logistic regression was used to evaluate sociodemographic and clinical factors associated with CR enrollment.

MAIN OUTCOMES AND MEASURES We used Andersen-Gill models to evaluate the association of CR enrollment with 1-year hospitalization risk and Cox regression models to evaluate the association of CR enrollment with 1-year mortality risk.

RESULTS A total of 41 369 Medicare beneficiaries (median [interquartile range] age, 73 [68-79] years; 16 935 [40.9%] female) underwent open valve surgery in the United States in 2014. Fewer than half of patients (17 855 [43.2%]) who had valve surgery enrolled in CR programs. Several racial/ethnic groups had lower odds of enrolling in CR programs after valve surgery compared with white patients, including Asian patients (odds ratio [OR], 0.36 [95% CI, 0.28-0.47]), black patients (OR, 0.60 [95% CI, 0.54-0.67]), and Hispanic patients (OR, 0.36 [95% CI, 0.28-0.46]). Patients undergoing concomitant coronary artery bypass grafting had higher odds of CR enrollment (OR, 1.26 [95% CI, 1.20-1.31]) than those without the concomitant coronary artery bypass graft procedure, as did patients in the Midwest census region (OR, 2.40 [95% CI, 2.28-2.54]) compared with those in the South (reference). Cardiac rehabilitation enrollment was associated with fewer hospitalizations within 1 year of discharge (hazard ratio, 0.66 [95% CI, 0.63-0.69] after multivariable adjustment). Enrollment was also associated with a 4.2% absolute decrease in 1-year mortality risk (hazard ratio, 0.39 [95% CI, 0.35-0.44] after multivariable adjustment).

CONCLUSIONS AND RELEVANCE Fewer than half of Medicare beneficiaries undergoing cardiac valve surgery enroll in CR programs, and there are marked racial/ethnic disparities among those that do. Cardiac rehabilitation is associated with decreased 1-year cumulative hospitalization and mortality risk after valve surgery. These results invite further study on barriers to CR enrollment in this population.

Invited Commentary

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Cardiac rehabilitation (CR), a comprehensive program of supervised exercise, cardiac risk factor modification, and psychosocial support, is widely underused in the United States.[1] Cardiac rehabilitation is covered by Medicare after acute myocardial infarction and 3 types of cardiac surgery: heart transplant, coronary artery bypass grafting (CABG), and cardiac valve surgery (CVS).[2] Patients undergoing CVS who participate in CR programs experience improvements in exercise capacity similar to those of people undergoing CABG.[3,4] The highest comparative CR enrollment rates are seen after CABG (approximately 40% of eligible patients)[5] and heart transplant (approximately half of eligible patients)[6]; CR enrollment after CVS is not well described. In this study, we evaluated Medicare beneficiaries' CR use after CVS in the United States. We also characterized the association of CR with 1-year cumulative hospitalizations and mortality. We hypothesized that CR is associated with a decreased risk of hospitalization and mortality in these patients.

Key Points

Question What is the association of cardiac rehabilitation with hospitalizations and mortality after cardiac valve surgery?

Findings In this cohort study of Medicare beneficiaries undergoing cardiac valve surgery in 2014, 43% participated in cardiac rehabilitation programs after discharge. Enrollment in cardiac rehabilitation was associated with a 34% relative decrease in hospitalizations within 1 year of discharge and a 4.2% absolute (61% relative) decrease in 1-year mortality risk.

Meaning Cardiac rehabilitation is associated with lower hospitalization and mortality risk after cardiac valve surgery but is underused in this population.

Methods

Study Design and Data Source

We conducted an observational cohort study to evaluate current use of CR among Medicare beneficiaries undergoing CVS and the association of CR enrollment with hospitalizations and mortality in this population. We obtained data regarding CR use among Medicare beneficiaries undergoing CVS in the United States from the 2013-2015 Medicare 100% Limited Data Set files. The institutional review board of Vanderbilt University Medical Center granted the study an exempt determination with a waiver of informed consent because of the large size of the data set.

Setting and Participants

The study population included Medicare beneficiaries who resided in the United States and were enrolled in 2014 because they were age 65 years or older or had qualifying disabilities. Inclusion in the study was based on a discharge diagnosis code (*International Classification of Diseases, Ninth Revision* codes 35.11, 35.12, 35.13, 35.14, 35.21, 35.22, 35.23, 35.24, 35.25, 35.26, 35.27, and 35.28) or procedure code (*Current Procedure Terminology* codes 33400, 33401, 33403, 33405, 33406, 33410, 33411, 33412, 33413, 33422, 33425, 33426, 33427, 33430, 33460, 33463, 33464, 33465, 33468, 33472, 33474, and 33475) for open replacement, repair, or valvuloplasty of the aortic, mitral, tricuspid, or pulmonary valves. We excluded Medicare beneficiaries who did not have uninterrupted fee-for-service coverage until death or for 1 year following discharge, those who attended any CR sessions in the year prior to CVS, and those who died within 30 days of discharge.

Variables

Enrollment in CR programs (a yes/no measure) was the primary exposure. We searched Medicare outpatient Limited Data Set files for CR claims (*Current Procedure Terminology* codes 93797, 93798, G0422, G0423, or S9472) within 1 year after discharge from the CVS hospitalization. Cardiac rehabilitation as a continuous variable (as a number of sessions attended) was characterized as a secondary exposure. Secondary outcomes included hospitalizations occurring within 1 year of discharge after CVS and all-cause mortality within 1 year of discharge after CVS, as ascertained from death dates in the Medicare denominator file. We also obtained sociodemographic characteristics from the denominator file. We characterized comorbidity burden with Elixhauser Comorbidity Index groups present during CVS and the preceding 12 months using *International Classification of Diseases, Ninth Revision* codes, as described previously.[7] We used the American Hospital Association Annual Survey of Hospitals to evaluate whether hospitals offering CVS had a CR program.[8] Socioeconomic status was characterized with median income from the patient's county of residence, as obtained from the United States Census Bureau Small Area Income and Poverty Estimates for 2014.[9]

Statistical Methods

We used logistic regression to assess determinants of CR enrollment and linear regression to evaluate factors associated with the number of CR sessions attended. Since Medicare beneficiaries could be hospitalized multiple times in the year after CVS, we used an Andersen-Gill model with a robust sandwich covariance estimator to model the association of participating in CR with 1-year cumulative hospitalization risk after adjusting for covariates.[10,11] Enrollment in CR was used as a time-varying exposure in these models. All individuals in the sample were considered CR nonparticipants at baseline and became exposed to CR on the date of the first CR session. We chose this approach (the Mantel-Byar method) to minimize immortal person-time bias.[12,13] To assess the association between CR participation and 1-year mortality, we constructed an adjusted Cox proportional-hazards regression model with CR enrollment as a time-varying exposure. Rehospitalization and mortality analyses were stratified by valve type, concomitant CABG, and discharge location to assess whether associations differed by these factors.

Bias

As a sensitivity analysis to further address observed confounding factors, we created marginal structural models with inverse

probability of treatment weighting.[14] In these models, we divided follow-up into 1-week blocks. Samples were reweighted at the beginning of each interval, allowing us to estimate the mean treatment effect associated with CR by standardizing the sample using CR participants at each point as the reference population. We also used instrumental variable analyses to account for potential unobserved confounding factors. Density of CR centers per state was used as an instrumental variable, because this variable was highly associated with CR initiation ($t_{28,868} = -35.47$ per Satterthwaite method for unequal variances; $P < .001$) and unassociated with 1-year mortality.

We reported E-values[15] to characterize the minimum strength of association that an unmeasured confounding factor would need to have with CR and 1-year cumulative hospitalization or mortality risk to fully explain away an exposure-specific association between CR and these outcomes. We also conducted analyses to measure the sensitivity of the association of CR with mortality to residual confounding from frailty and other unmeasured variables.[16] These analyses make statistical inferences about the true association of CR with mortality by specifying distributions of unmeasured confounding factors and their association with mortality risk.

All analyses used SAS version 9.4 (SAS Institute). A 2-sided *P* value less than .05 was considered significant.

Results

Participants

There was a total of 49 651 Medicare beneficiaries undergoing CVS in 2014. We excluded 555 patients who attended CR in the year prior to CVS, 4581 patients who did not have uninterrupted fee-for-service Medicare coverage, 78 patients who did not live in the United States, and 3068 patients who died in the hospital or within 30 days of discharge. The final sample size was 41 369 patients.

Descriptive Data

The median age of the cohort was 73 [interquartile range (IQR), 68-79] years, and 16 935 patients who had had CVS were female (40.9%; **Table 1**). Most patients undergoing CVS had undergone aortic valve procedures (28 238 [68.3%]), followed by those who had undergone mitral valve replacement (5068 [12.3%]), mitral valve repair (3799 [9.2%]), and tricuspid valve surgery (484 [1.2%]). One-year mortality (excluding patients who died while hospitalized or within 30 days of discharge) was 2726 deaths (6.6% of the full sample) over 39 842 person-years of follow-up. Among patients undergoing CVS, 16 964 patients (41.0%) were hospitalized at least once in the year after discharge.

Cardiac Rehabilitation Use

A total of 17 855 Medicare beneficiaries (43.2%) undergoing CVS enrolled in CR programs (**Table 2**). The median number of sessions attended among CR enrollees was 32 (IQR, 18-36) sessions. After multivariable adjustment, patients who had had CVS with a concomitant CABG procedure had higher odds of enrolling in CR programs (odds ratio [OR], 1.26 [95% CI, 1.20-1.31]). There were marked differences in CR enrollment by racial/ethnic groups, with Asian patients (OR, 0.36 [95% CI, 0.28-0.47]), black patients (OR, 0.60 [95% CI, 0.54-0.67]), and Hispanic patients (OR, 0.36 [95% CI, 0.28-0.46]) much less likely to attend CR than white patients. Patients undergoing CVS in the Midwest census region were much more likely to attend CR programs (OR, 2.40 [95% CI, 2.28-2.54] compared with those in the South census region [reference]). The median (IQR) number of CR sessions attended showed no significant difference among types of valve surgery. The median time between discharge and the first CR session was 44 (IQR, 29-66) days.

Cardiac Rehabilitation and 1-Year Hospitalization Risk

Adjusted hospitalizations within 1 year of discharge after CVS, stratified by CR participation, are displayed in the **Figure**. Enrollment in a CR program was associated with a decreased risk of 1-year hospitalizations (hazard ratio [HR], 0.66 [95% CI, 0.63-0.69]) after multivariable adjustment (**Table 3**).

The association between CR and cumulative 1-year hospitalization risk was of a similar magnitude when models were stratified by aortic valve surgery (HR, 0.68 [95% CI, 0.64-0.71]), mitral valve repair (HR, 0.64 [95% CI, 0.58-0.76]), mitral valve replacement (HR, 0.62 [95% CI, 0.55-0.69]), tricuspid valve surgery (HR, 0.64 [95% CI, 0.46-0.89]), and surgery on multiple valves (HR, 0.66 [95% CI, 0.59-0.74]). (There were not enough pulmonary valve surgeries for an analysis limited to this valve type.)

There was a similar association between CR and decreased hospitalization risk when patients who had undergone valve surgery were stratified into a group that had undergone concomitant CABG (HR, 0.69 [95% CI, 0.64-0.73]) compared with those undergoing isolated valve surgery (HR, 0.64 [95% CI, 0.61-0.68]). There was also a similar association between CR and hospitalization risk when patients who had had CVS were stratified into those who were discharged home (HR, 0.69 [95% CI, 0.65-0.73]) compared with those that were discharged to inpatient rehabilitation facilities, skilled nursing facilities, or other hospitals (HR, 0.64 [95% CI, 0.61-0.68]).

Cardiac Rehabilitation and 1-Year Mortality Risk

Cardiac rehabilitation was associated with a 4.2% absolute decrease in 1-year mortality risk in patients who had undergone CVS (HR, 0.39 [95% CI, 0.35-0.44] after multivariable adjustment; **Table 4**). One-year mortality was 2338 of 23 514 CR nonparticipants (9.9%) and 388 of 17 855 CR participants (2.2%). Adjusted 1-year mortality, stratified by CR participation, is displayed in the Figure.

The association between CR and cumulative 1-year hospitalization risk was of a similar magnitude when models were stratified by aortic valve surgery (HR, 0.39 [95% CI, 0.34-0.45]), mitral valve repair (HR, 0.33 [95% CI, 0.22-0.51]), mitral valve replacement (HR, 0.38 [95% CI, 0.29-0.50]), and multiple valve replacement (HR, 0.44 [95% CI, 0.34-0.62]). There were not enough deaths after tricuspid valve surgery or pulmonic valve surgery for a stratified analysis.

There was a similar association between CR and decreased mortality risk when patients who had valve surgery

Table 1. Baseline Characteristics of Medicare Beneficiaries Undergoing Cardiac Valve Surgery in 2014[a]

Characteristic	Patients, No. (%)		
		Cardiac Rehabilitation	
	All	Nonparticipants	Participants
Total	41 369	23 514 (56.8)	17 855 (43.2)
Demographic			
Age, median (IQR), y	73 (68-79)	73 (67-79)	73 (68-78)
Female	16 935 (40.9)	10 185 (43.3)	6750 (37.8)
Race			
Asian	357 (0.9)	286 (1.2)	71 (0.4)
Black	2305 (5.6)	1758 (7.5)	547 (3.1)
Hispanic	437 (1.1)	359 (1.5)	78 (0.4)
Native American	160 (0.4)	119 (0.5)	41 (0.2)
Other	797 (1.9)	455 (1.9)	342 (1.9)
White	37 313 (90.2)	20 537 (87.3)	16 776 (94.0)
County income, median (IQR), $	52 945 (45 733-62 591)	51 999 (44 258-61 797)	54 309 (47 083-63 478)
Census region			
Midwest	9924 (24.0)	4198 (17.9)	5726 (32.1)
Northeast	9106 (22.0)	5467 (23.3)	3639 (20.4)
West	7218 (17.5)	4239 (18.0)	2979 (16.7)
South	15 121 (36.5)	9610 (40.9)	5511 (30.9)
Clinical			
Type of valve surgery			
Aortic	28 238 (68.3)	15 603 (66.4)	12 635 (70.8)
Mitral repair	3799 (9.2)	2086 (8.9)	1713 (9.6)
Mitral replacement	5068 (12.3)	3167 (13.5)	1901 (10.7)
Pulmonary	65 (0.2)	49 (0.2)	16 (0.1)
Tricuspid	484 (1.2)	352 (1.5)	132 (0.7)
Multiple	3715 (9.0)	2257 (9.6)	1458 (8.2)
Concomitant coronary artery bypass grafting	14 982 (36.2)	8132 (34.6)	6850 (38.4)
Cardiac rehabilitation program at surgical hospital	37 370 (90.6)	20 850 (89.0)	16 520 (92.8)
Discharged to inpatient rehabilitation or skilled nursing facility	15 613 (37.7)	10 289 (43.8)	5324 (29.8)
Length of stay, median (IQR), d	8 (6-12)	9 (6-14)	7 (5-10)
Comorbidities			
Alcohol dependence	1395 (3.4)	930 (4.0)	465 (2.6)
Anemia	2135 (5.2)	1419 (6.0)	716 (4.0)
Cardiac arrhythmia	30 040 (72.6)	17 222 (73.2)	12 818 (71.8)
Chronic pulmonary disease	17 065 (41.3)	10 567 (44.9)	6498 (36.4)
Congestive heart failure	20 123 (48.6)	12 681 (53.9)	7442 (41.7)
Depression	5340 (12.9)	3364 (14.3)	1976 (11.1)
Diabetes	13 614 (32.9)	8289 (35.3)	5325 (29.8)
Drug abuse	992 (2.4)	736 (3.1)	256 (1.4)
Hypertension	35 027 (84.7)	20 114 (85.5)	14 913 (83.5)
Hypothyroidism	7443 (18.0)	4229 (18.0)	3214 (18.0)
Liver disease	1760 (4.3)	1211 (5.2)	549 (3.1)
Obesity	9235 (22.3)	5253 (22.3)	3982 (22.3)
Other neurological disorders	3898 (9.4)	2665 (11.3)	1233 (6.9)
Peripheral vascular disease	9357 (22.6)	5615 (23.9)	3742 (21.0)
Pulmonary circulation disorders	9976 (24.1)	6345 (27.0)	3631 (20.3)
Renal failure	10 184 (24.6)	6682 (28.4)	3502 (19.6)
Rheumatoid arthritis	1969 (4.8)	1166 (5.0)	803 (4.5)
Solid tumor	967 (2.3)	579 (2.5)	388 (2.2)
Weight loss	2921 (7.1)	2176 (9.3)	745 (4.2)

Abbreviation: IQR, interquartile range.

[a] Percentages are column percentages.

Table 2. Association of Cardiac Valve Surgery Type With Cardiac Rehabilitation Enrollment and Attendance Among Medicare Beneficiaries

Characteristic	Proportion of Patients Enrolling in Cardiac Rehabilitation, %	Enrollment in a Cardiac Rehabilitation Program		Sessions Attended, Median (IQR)	Change in Sessions Attended (95% CI)[a]	*P* Value
		Odds Ratio (95% CI)[a]	*P* Value			
All	17 855 (43.2)	NA	NA	32 (18-36)	NA	NA
Type of cardiac valve surgery						
Aortic	12 635 (44.7)	1 [Reference]	<.001	32 (18-36)	0 [Reference]	.76
Mitral repair	1713 (45.1)	1.05 (0.97-1.13)		32 (18-36)	0.32 (−0.29 to 0.93)	
Mitral replacement	1901 (37.5)	1.04 (0.97-1.12)		33 (17-36)	0.25 (−0.34 to 0.85)	
Tricuspid	132 (27.3)	0.81 (0.65-1.01)		28 (18-36)	−0.20 (−2.23 to 1.82)	
Pulmonary	16 (24.6)	0.46 (0.25-0.83)		23 (16-36)	2.50 (−3.25 to 8.26)	
Multiple	1458 (39.3)	1.16 (1.07-1.25)		32 (18-36)	0.29 (−0.38 to 0.95)	
Concomitant CABG	6850 (45.7)	1.26 (1.20-1.31)	<.001	33 (18-36)	0.46 (0.09 to 0.83)	.01
Demographic						
Age, per 5-y increase	NA	1.04 (1.03-1.06)	<.001	NA	0.70 (0.57 to 0.83)	<.001
Sex						
Male	11 105 (45.5)	1.17 (1.12-1.23)	<.001	33 (18-36)	1.08 (0.69 to 1.46)	<.001
Female	6750 (39.9)	1 [Reference]		31 (17-36)	0 [Reference]	
Race						
Asian	71 (19.9)	0.36 (0.28-0.47)	<.001	24 (12-35)	−3.26 (−5.99 to −0.53)	.002
Black	547 (23.7)	0.60 (0.54-0.67)		30 (12-36)	−1.24 (−2.26 to −0.21)	
Hispanic	78 (17.9)	0.36 (0.28-0.46)		27 (12-36)	−1.88 (−4.48 to 0.73)	
Native American	41 (25.6)	0.52 (0.36-0.75)		20 (9-30)	−4.60 (−8.19 to −1.01)	
Other	342 (42.9)	0.94 (0.81-1.09)		31 (18-36)	−0.03 (−1.29 to 1.23)	
White	16 776 (45.0)	1 [Reference]		32 (18-36)	0 [Reference]	
Median county income, per $10 000 increase		1.09 (1.07-1.10)	<.001	NA	0.09 (−0.04 to 0.21)	.17
Census region						
Midwest	5726 (57.7)	2.40 (2.28-2.54)	<.001	30 (18-36)	−1.12 (−1.56 to −0.69)	<.001
Northeast	3639 (40.0)	1.06 (1.00-1.13)		33 (19-36)	−0.33 (−0.84 to 0.19)	
West	2979 (41.3)	1.10 (1.04-1.17)		32 (16-36)	−1.37 (−1.90 to −0.84)	
South	5511 (36.5)	1 [Reference]		34 (18-36)	0 [Reference]	
Clinical						
Length of stay, per 5-d increase	NA	0.80 (0.79-0.82)	<.001	NA	0.13 (−0.05 to 0.31)	.17
Discharged to inpatient rehabilitation or skilled nursing facility	5324 (34.1)	0.66 (0.62-0.69)	<.001	33 (19-36)	0.47 (0.06 to 0.88)	.02
Comorbidities						
Alcohol dependence	465 (33.3)	0.76 (0.67-0.86)	<.001	29 (15-36)	−0.97 (−2.06 to 0.13)	.08
Anemia	716 (33.5)	0.92 (0.83-1.02)	.10	31 (18-36)	0.38 (−0.51 to 1.27)	.40
Cardiac arrhythmia	12,818 (42.7)	1.10 (1.05-1.16)	<.001	32 (18-36)	0.14 (−0.26 to 0.54	.49
Chronic pulmonary disease	6498 (38.1)	0.89 (0.84-0.94)	<.001	31 (17-36)	−1.04 (−1.52 to −0.57)	<.001
Congestive heart failure	7442 (37.0)	0.84 (0.80-0.88)	<.001	32 (17-36)	−0.19 (−0.57 to 0.19)	.34
Depression	1976 (37.0)	0.93 (0.87-0.99)	.03	28 (14-36)	−1.37 (−1.93 to −0.81)	<.001
Diabetes	5325 (39.1)	0.87 (0.84-0.92)	<.001	32 (17-36)	−0.21 (−0.60 to 0.19)	.31
Drug abuse	256 (25.8)	0.67 (0.58-0.78)	<.001	24 (12-36)	−2.15 (−3.61 to −0.69)	.004
Hypertension	14 913 (42.6)	0.95 (0.90-1.01)	.10	32 (18-36)	0.42 (−0.05 to 0.90)	.08
Hypothyroidism	3214 (43.2)	1.10 (1.04-1.17)	<.001	33 (18-36)	0.19 (−0.27 to 0.65)	.42
Liver disease	549 (31.2)	1.02 (0.91-1.14)	.80	31 (17-36)	−0.09 (−1.10 to 0.93)	.87
Obesity	3982 (43.1)	1.17 (1.11-1.24)	<.001	31 (17-36)	0.02 (−0.41 to 0.45)	.92

(continued)

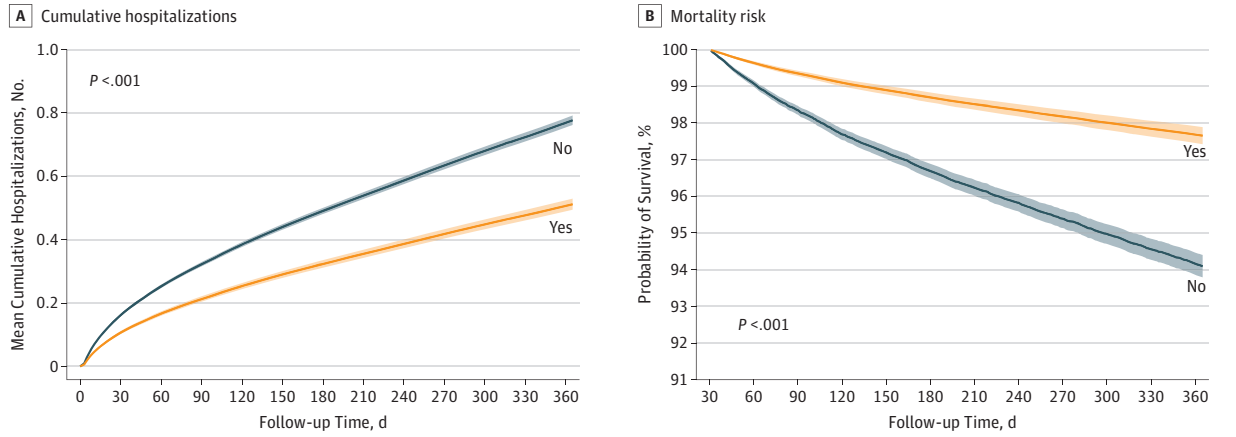
Table 2. Association of Cardiac Valve Surgery Type With Cardiac Rehabilitation Enrollment and Attendance Among Medicare Beneficiaries (continued)

Characteristic	Proportion of Patients Enrolling in Cardiac Rehabilitation, %	Enrollment in a Cardiac Rehabilitation Program		Sessions Attended, Median (IQR)	Change in Sessions Attended (95% CI)[a]	*P* Value
		Odds Ratio (95% CI)[a]	*P* Value			
Other neurological disorders	1233 (31.6)	0.85 (0.78-0.91)	<.001	32 (18-36)	0.20 (−0.49 to 0.89)	.57
Peripheral vascular disease	3742 (40.0)	0.92 (0.87-0.96)	<.001	31 (18-36)	−0.19 (−0.62 to 0.24)	.38
Pulmonary circulation disorders	3631 (36.4)	0.98 (0.92-1.05)	.61	33 (17-36)	0.80 (0.23 to 1.37)	.006
Renal failure	3502 (34.4)	0.84 (0.79-0.88)	<.001	32 (17-36)	−0.69 (−1.14 to −0.23)	.003
Rheumatoid arthritis	803 (40.8)	1.01 (0.92-1.12)	.82	29 (16-36)	−0.94 (−1.77 to −0.11)	.03
Solid tumor	388 (40.1)	0.94 (0.82-1.08)	.38	31 (18-36)	−0.20 (−1.38 to 0.98)	.74
Weight loss	745 (25.5)	0.77 (0.70-0.84)	<.001	33 (18-36)	0.11 (−0.78 to 1.00)	.81

Abbreviations: CABG, coronary artery bypass grafting; IQR, interquartile range.

[a] Adjusted for all listed variables.

Figure. Hospitalization and Mortality Risk for Medicare Beneficiaries Undergoing Cardiac Valve Surgery, Stratified by Cardiac Rehabilitation Enrollment



A, Cumulative hospitalizations were calculated using an Andersen-Gill model. B, Mortality risk was calculated using a Cox regression model. Both models were adjusted for valve surgery type, age, sex, race, census region, median county income, comorbidities, discharge to an inpatient rehabilitation facility or skilled nursing facility, and length of stay during valve surgery. Shaded areas represent 95% CIs.

were stratified by those undergoing concomitant CABG (HR, 0.39 [95% CI, 0.33-0.46]) compared with those undergoing isolated valve surgery (HR, 0.39 [95% CI, 0.34-0.45]). The magnitude of the decrease in mortality risk associated with CR was slightly smaller in patients who had had CVS and were discharged to home (HR, 0.46 [95% CI, 0.39-0.54]) compared with that were discharged to inpatient rehabilitation facilities, skilled nursing facilities, or other hospitals (HR, 0.35 [95% CI, 0.30-0.40]).

Potential Confounding Factors

We conducted numerous sensitivity analyses to account for both observed and unobserved confounding. First, we used a marginal structural model to account for observed confounding factors with regard to the association between CR and 1-year mortality. The marginal structural model demonstrated a similar association (HR, 0.42 [95% CI, 0.37-0.47]; $P < .001$), as observed in the primary analysis.

Second, we accounted for unobserved confounding using the density of CR centers at the state level as an instrumental variable. The association between CR and 1-year mortality in the instrumental variable analysis (HR, 0.54 [95% CI, 0.37-0.80]; $P = .002$) was slightly attenuated from the primary analysis but retained statistical significance.

Third, we calculated E-values[15] to further illuminate potential associations with unobserved confounding factors. We calculated an E-value of 2.00 for the association of CR with cumulative risk of hospitalizations over 1 year and an E-value of 4.57 for the association of CR with 1-year mortality risk. In other words, a potential confounding factor would need to have a minimum risk ratio of 2.00 to fully explain away the association between CR enrollment and 1-year hospitalizations, above and beyond the measured confounding factors, and a minimum risk ratio of 4.57 to do the same for 1-year mortality risk.

Lastly, we conducted an additional sensitivity analysis[16] to specifically investigate the potential association of an im-

Table 3. Association of Cardiac Rehabilitation Enrollment With Cumulative 1-Year Hospitalization Risk Among Medicare Beneficiaries Undergoing Cardiac Valve Surgery

Characteristic	Cumulative 1-y Hospitalization Risk	
	Hazard Ratio (95% CI)[a]	*P* Value
Cardiac rehabilitation enrollment	0.66 (0.63-0.69)	<.001
Demographic		
Age (5-y increase)	0.96 (0.95-0.97)	<.001
Sex		
Male	0.95 (0.92-0.98)	.003
Female	1 [Reference]	
Race		
Asian	0.93 (0.80-1.08)	<.001
Black	1.13 (1.06-1.21)	
Hispanic	1.13 (0.99-1.30)	
Native American	1.20 (0.95-1.51)	
Other	0.94 (0.83-1.07)	
White	1 [Reference]	
Median county income ($10 000 increase)	1.00 (0.99-1.01)	.90
Census region		
Midwest	1.03 (0.99-1.07)	<.001
Northeast	0.96 (0.92-1.01)	
West	0.86 (0.82-0.90)	
South	1 [Reference]	
Clinical		
Type of valve surgery		
Aortic	1 [Reference]	<.001
Mitral repair	0.98 (0.93-1.04)	
Mitral replacement	1.19 (1.14-1.25)	
Tricuspid	1.20 (1.07-1.35)	
Pulmonary	0.93 (0.55-1.59)	
Multiple	1.14 (1.08-1.20)	
Concomitant coronary artery bypass graft	1.07 (1.04-1.10)	<.001
Length of stay (5-d increase)	1.07 (1.06-1.08)	<.001
Discharged to inpatient rehabilitation or skilled nursing facility	1.35 (1.30-1.40)	<.001
Comorbidities		
Alcohol dependence	1.08 (0.99-1.18)	.09
Anemia	1.12 (1.05-1.20)	<.001
Cardiac arrhythmia	1.17 (1.12-1.21)	<.001
Chronic pulmonary disease	1.23 (1.18-1.28)	<.001
Congestive heart failure	1.23 (1.19-1.27)	<.001
Depression	1.18 (1.13-1.23)	<.001
Diabetes	1.19 (1.15-1.23)	<.001
Drug abuse	1.50 (1.37-1.64)	<.001
Hypertension	1.10 (1.05-1.16)	<.001
Hypothyroidism	1.05 (1.01-1.09)	.02
Liver disease	1.15 (1.07-1.23)	<.001
Obesity	1.05 (1.01-1.09)	.02
Other neurological disorders	1.16 (1.11-1.22)	<.001
Peripheral vascular disease	1.19 (1.15-1.23)	<.001
Pulmonary circulation disorders	0.99 (0.94-1.03)	.57
Renal failure	1.40 (1.35-1.45)	<.001
Rheumatoid arthritis	1.28 (1.20-1.36)	<.001
Solid tumor	1.19 (1.09-1.30)	<.001
Weight loss	1.09 (1.03-1.15)	.003

[a] Hazard ratios derived from the Andersen-Gill model with robust sandwich covariance estimator (or proportional means model) adjusted for all listed covariates.

portant confounding factor, frailty, with our findings. Prior work identified a 4% prevalence of frailty in patients who had cardiac surgery, which was associated with increased medium-term mortality risk (HR, 1.5 [95% CI, 1.1-2.2]; $P < .01$).[17] Conservatively assuming 0% frailty prevalence in people who participated in CR and 40% in nonparticipants, frailty would need to have a HR for 1-year mortality risk of 4.18 to render inconclusive the observed, multivariable-adjusted outcome of CR. Thus, frailty would need to be essentially nonexistent in people who participated in CR, and the residual association of frailty would need to be stronger than the main association suggested by the literature. These results indicate that, while it is possible residual confounding is causing some overestimation of the outcome of CR participation, it is highly unlikely it is causing the observed statistically significant association.

Discussion

To our knowledge, this is the first study to evaluate CR use after CVS at the national level in the United States. Among Medicare beneficiaries, 43% of patients undergoing CVS enrolled in CR programs. After adjustment, patients who had undergone CVS in the Midwest census region were more than twice as likely to attend CR as others. Programs of CR are associated with a lower risk of 1-year hospitalizations and mortality in patients who had had CVS. Although it is not possible to account for all potential confounding factors, sensitivity analyses adjusting for observed confounding and unobserved confounding demonstrated similar results.

CVS Compared With Other CR Indications

While CR is generally underused, CR enrollment rates vary significantly by indication. One of the most recently approved indications, stable systolic heart failure, has CR enrollment rates of less than 10%.[18] The highest reported Medicare CR enrollment rates occur in the setting of heart transplant, where approximately half of patients attend CR programs,[6] and CR enrollment rates are 35% to 40% after CABG.[19-22] Although CR enrollment after CVS is still low, this analysis demonstrates that this population has some of the highest CR enrollment rates seen to date, with the exception of patients who had had heart transplants.

Table 4. Association of 1-Year Mortality Risk With Cardiac Rehabilitation Enrollment Among Medicare Beneficiaries Undergoing Cardiac Valve Surgery in 2014

Characteristic	1-y Mortality Risk	
	Hazard Ratio (95% CI)[a]	*P* Value
Cardiac rehabilitation enrollment	0.39 (0.35-0.44)	<.001
Demographic		
Age (5-y increase)	1.05 (1.03-1.08)	<.001
Sex		.04
Male	1.09 (1.01-1.19)	
Female	1 [Reference]	
Race		
Asian	1.12 (0.78-1.60)	.55
Black	1.04 (0.89-1.21)	
Hispanic	1.12 (0.82-1.53)	
Native American	1.29 (0.80-2.09)	
Other	1.22 (0.94-1.58)	
White	1 [Reference]	
Median county income ($10 000 increase)	0.99 (0.97-1.02)	.54
Census region		
Midwest	1.09 (0.99-1.21)	<.001
Northeast	0.81 (0.72-0.90)	
West	0.96 (0.86-1.08)	
South	1 [Reference]	
Clinical		
Type of valve surgery[b]		
Aortic	1 [Reference]	<.001
Mitral repair	0.96 (0.83-1.12)	
Mitral replacement	1.24 (1.11-1.39)	
Tricuspid	1.10 (0.82-1.48)	
Multiple	1.18 (1.04-1.34)	
Concomitant coronary artery bypass graft	1.14 (1.05-1.23)	.002
Length of stay (5-d increase)	1.13 (1.11-1.15)	<.001
Discharged to inpatient rehabilitation or skilled nursing facility	1.92 (1.76-2.10)	<.001
Comorbidities		
Alcohol dependence	1.03 (0.84-1.26)	.81
Anemia	1.03 (0.90-1.19)	.68
Cardiac arrhythmia	1.27 (1.14-1.41)	<.001
Chronic pulmonary disease	1.25 (1.13-1.39)	<.001
Congestive heart failure	1.32 (1.21-1.45)	<.001
Depression	0.96 (0.86-1.07)	.49
Diabetes	1.23 (1.14-1.34)	<.001
Drug abuse	1.35 (1.11-1.64)	.002
Hypertension	0.95 (0.84-1.08)	.46
Hypothyroidism	1.05 (0.95-1.15)	.37
Liver disease	1.31 (1.13-1.51)	<.001
Obesity	0.87 (0.79-0.96)	.004
Other neurological disorders	1.41 (1.27-1.56)	<.001
Peripheral vascular disease	1.22 (1.12-1.33)	<.001
Pulmonary circulation disorders	0.99 (0.89-1.11)	.87
Renal failure	1.61 (1.48-1.76)	<.001
Rheumatoid arthritis	1.22 (1.05-1.43)	.01
Solid tumor	1.49 (1.21-1.82)	<.001
Weight loss	1.48 (1.33-1.65)	<.001

(continued)

Table 4. Association of 1-Year Mortality Risk With Cardiac Rehabilitation Enrollment Among Medicare Beneficiaries Undergoing Cardiac Valve Surgery in 2014 (continued)

[a] Hazard ratios derived from a Cox regression model means model were adjusted for all listed covariates.

[b] Pulmonary valve effects are not displayed because of the low number of deaths.

Cardiac Rehabilitation Enrollment

Aortic and mitral valve surgery had relatively high CR enrollment rates as compared with other indications, but the proportion of patients enrolling in CR after tricuspid or pulmonary valve surgery was considerably lower. This may be attributable to the fact that tricuspid and pulmonary valve pathology is less frequently seen in association with ischemic heart disease.[23,24] Patients who had undergone CVS with concomitant CABG had a 26% higher odds of enrolling in CR programs, supporting this idea.

The Midwest had a far higher proportion of patients who had had CVS enrolling in CR programs. This geographic pattern in CR use has been noted in prior work across a variety of other indications.[5,21,22] Apart from geographic variation, the most striking differences in CR enrollment in this study were associated with race and ethnicity. Asian and Hispanic patients were less than half as likely to enroll in CR as white patients; black patients had a 40% lower odds of doing so. For comparison, the landmark study by Suaya et al[22] of CR enrollment among Medicare beneficiaries with ischemic heart disease in 1997 demonstrated that nonwhite patients had a 33% lower odds of initiating CR. This work demonstrates that racial/ethnic disparities in CR enrollment among Medicare patients undergoing CVS are at least as large as in ischemic heart disease.

Cardiac Rehabilitation Attendance

Higher CR attendance (ie, attending a number of sessions closer to the generally recommended program of 36 sessions) is associated with decreased mortality.[20,21] This analysis demonstrated that the median number of sessions attended among enrollees is approximately 32 across most sociodemographic factors and comorbidities. These data indicate that programs designed to increase CR use in this population are perhaps best directed toward enrollment, as opposed to attendance, since patients who had had CVS and were enrolling in CR programs tend to attend similar numbers of sessions.

Cardiac Rehabilitation and Outcomes After CVS

Cardiac rehabilitation was associated with a 34% lower risk of cumulative hospitalizations in the year after CVS among Medicare beneficiaries. There are few clinical trials focusing on hospitalizations after CR because of clinical equipoise considerations. However, 1 study[25] identified a 36% relative decrease

in the risk of 1-year hospitalizations in patients admitted with heart failure, which is similar to our own results. There are many mechanisms by which CR might decrease hospitalizations in patients who had undergone CVS, including increased surveillance by CR staff who might alert the patient's clinician in the event of deterioration, encouragement of medication adherence, and improvement in functional status.[2]

Cardiac rehabilitation was also associated with a 61% relative (4.2% absolute) decrease in 1-year mortality after CVS. Putting these results in context, Suaya et al[22] found that CR was associated with a 56% relative decrease in 1-year mortality in a regression model of Medicare beneficiaries with ischemic heart disease in 1997.[21] Our own prior work[6] found that CR is associated with a 57% relative decrease in 1-year mortality risk among ventricular assist device recipients. Therefore, these findings in patients who had undergone CVS are consistent with studies of other patient populations.

Of note, prior studies of smaller cohorts identified an association between CR and reduced mortality risk in patients undergoing valve surgery with concomitant CABG[26] but not those undergoing isolated valve surgery.[27] We found associations of similar magnitude between CR and mortality risk (as well as hospitalization risk) after stratifying analyses by patients who had valve surgery and had undergone concomitant CABG vs those who had valve surgery and did not have concomitant CABGs. These findings suggest that CR is beneficial in all patients undergoing valve surgery, as opposed to just those with ischemic heart disease.

Clinical and Policy Implications

This work has several implications at both the clinical and policy level. First, there are significant racial/ethnic disparities in CR enrollment among patients undergoing CVS. These results underscore the need to further understand barriers to CR in underserved populations. Second, the geographic variation in CR enrollment seen in patients undergoing CVS (with Medicare beneficiaries in the Midwest census region more than twice as likely to enroll in CR programs as those in other regions) represents an opportunity. By studying best practices in high-performing centers, perhaps CR enrollment can be optimized at other institutions. Lastly, this work is relevant to value-based health care delivery models. Cardiac rehabilitation will likely play an integral role in bundled services, including those associated with CVS.

Study Limitations

This study has limitations in addition to the potential confounding considerations. First, our study sample was limited to patients who had had CVS and were aged 65 years or older or had disability benefits; thus, this study may not be generalizable to younger patients. Second, the analyses were limited to patients who were enrolled in fee-for-service Medicare. However, most Medicare beneficiaries are still enrolled in fee-for-service programs.[28] Lastly, Medicare claims are not adjudicated. However, these data have been used to study many cardiovascular conditions and therapies in prior work.[5,6,21,22]

Conclusions

In summary, less than half of Medicare beneficiaries undergoing CVS enroll in CR programs. Cardiac rehabilitation is associated with a lower risk of hospitalizations and mortality in the year after CVS. We identified major racial/ethnic disparities and geographic variation in CR enrollment in this population. These results invite further study on barriers to CR enrollment in patients who have had CVS, as well as efforts to expand CR access to groups of patients who have had CVS and have particularly low enrollment rates.

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