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ORIGINAL ARTICLE

Association Between Cardiac Rehabilitation and 1-Year Mortality by Frailty Level in Medicare Beneficiaries

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BACKGROUND: Frailty before cardiovascular procedures is associated with poorer outcomes. While underutilized, cardiac rehabilitation (CR) is guideline-recommended for patients undergoing cardiovascular procedures and may help mitigate the effects of frailty. This study evaluated the association between preprocedural frailty and CR use, as well as the interaction of frailty and CR use on 1-year mortality.

METHODS: Medicare fee-for-service claims were queried for patients undergoing percutaneous or surgical revascularization or aortic valve replacement between July 2016 and December 2018. Patients who experienced mortality during the index admission or within 30 days of discharge were excluded. Patients were stratified into quartiles (Q1–Q4) using the validated claims-based frailty index (CFI). CR use was defined as attending any CR session within 1 year of discharge. Unadjusted comparisons and multivariable analyses were used to evaluate the relationship between frailty and CR use (CFI-Q4 versus CFI-Q1). An inverse probability treatment weighting model was used to determine if there was an interaction between CR, frailty, and 1-year mortality.

RESULTS: Overall CR use among the 501 049 beneficiaries was 37.7%; the average age was 75.9 years (SD, 7.3), and 37.0% were female. Increasing frailty was associated with decreased CR use (CFI-Q1: 49.7%, CFI-Q2: 42.2%, CFI-Q3: 35.3%, and CFI-Q4: 23.7%; $P<0.001$; adjusted odds ratio_{CFI-Q4 versus CFI-Q1}, 0.63 [95% CI, 0.62–0.64]). Unadjusted 1-year mortality was higher with increasing frailty (CFI Q1: 2.5%, CFI-Q2: 5.1%, CFI-Q3: 9.0%, and CFI Q4: 16.9%; $P<0.001$). After adjustment, the reduction in mortality associated with CR use was greater among frailer patients relative to less frail patients (CFI-Q4: 9.2% and CFI-Q1: 1.7%; $P<0.001$). CR use was associated with a significantly reduced association between CFI and 1-year mortality ($P<0.001$).

CONCLUSIONS: Preprocedural frailty is associated with lower CR use despite greater absolute benefits on 1-year mortality. Increasing CR use of frail Medicare beneficiaries may reduce 1-year mortality after cardiac interventions.

Key Words: activities of daily living ■ coronary artery bypass ■ frailty ■ quality of life ■ rehabilitation

Cardiac rehabilitation (CR) is a supervised, secondary prevention service aimed at improving outcomes after cardiac interventions.¹ CR is a class 1A recommendation after surgical or percutaneous revascularization and after surgical or transcatheter aortic valve replacement (TAVR).^{2,3} Contemporary data

suggest that CR is associated with improved clinical outcomes, exercise tolerance, and health-related quality of life.^{4–6} Unfortunately, CR remains underutilized, with less than one-third of patients attending at least 1 CR session.^{2,7,8} The Centers for Disease Control and Prevention, the Million Hearts Campaign, and many

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WHAT IS KNOWN

- Preprocedural frailty is an important risk factor for poor outcomes following cardiovascular interventions.
- Referral of frail patients to cardiac rehabilitation (CR) is a contested topic, with some suggesting that there is a point at which a patient may be too frail to derive benefit from graded exercise therapy, and with others suggesting that the purported benefits of CR are most salient for frail individuals.

WHAT THE STUDY ADDS

- This study utilized a large national cohort and shows that frail patients were less likely to attend CR, took longer to enroll in CR, and were less likely to complete all sessions after starting CR.
- Frail patients who attended CR experienced a higher associated reduction in risk of 1-year mortality, suggesting that frail patients derive greater benefit from CR despite lower usage.

Nonstandard Abbreviations and Acronyms

CABG	coronary artery bypass grafting
CFI	claims-based frailty index
CR	cardiac rehabilitation
IPTW	inverse probability treatment weighting
MBSF	medicare beneficiary summary data files
PCI	percutaneous coronary intervention
SAVR	surgical aortic valve replacement
TAVR	transcatheter aortic valve replacement

other national agencies have identified low CR use as a quality gap in patients undergoing cardiac interventions.⁹ Identifying high-risk patient populations that are low utilizers of CR is important in developing interventions for improving CR use.

Preprocedural frailty may be an important risk factor for lower CR use, but the association between frailty and CR use is not well described. Frailty, defined as an age-related increase in vulnerability to stressors and a decrease in physiological reserve,¹⁰ is associated with poor patient outcomes in both surgical and interventional cohorts.¹¹ Referral of frail patients to CR is a contested topic, with some suggesting that there is a point at which a patient could be too frail to derive benefit from graded exercise therapy,¹² and with others suggesting that the purported benefits of CR are most salient for frail individuals.¹³ CR is thought to mitigate hospital-associated deconditioning, increase cardiovascular reserve, decrease sarcopenia, improve the ability to perform activities of daily living, and provide targeted

review of medications in the setting of polypharmacy, all of which are important among frail individuals.¹⁴⁻¹⁸ Despite the potential benefits that CR offers to frail individuals, contemporary data from single institution cohorts suggest that older, frail patients are less likely to be referred to CR or attend any session and have poorer adherence rates after starting a CR program, compared with younger, healthier individuals.¹⁹⁻²¹ Given an aging cardiac surgical and interventional population, understanding frailty's effect on procedural outcomes and interventions is paramount to improving overall quality of cardiovascular health care delivery.

This study evaluated the association between frailty, CR use, and 1-year mortality for patients undergoing both interventional and open surgical cardiac procedures in a large national data set of Medicare beneficiaries.

MATERIALS AND METHODS

Data Sources and Sample

The University of Michigan institutional review board deemed this quality improvement project exempt from human subjects research review (HUM0017554). The authors (M.P.T. and H.H.) had access to all the data in the study and take full responsibility for its integrity and the data analysis; this investigation was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. The data, analytic code, and study materials will not be made available to other researchers for purposes of reproducing the results.

Medicare administrative claims data (data use agreement No. RSCH-2017-51285) was queried from July 2016 to December 2018 and included inpatient facility, carrier (eg, advanced practice providers and physician services), outpatient facility, hospice care, and Medicare beneficiary summary data files (MBSF). Beneficiaries who underwent inpatient percutaneous coronary intervention (PCI), TAVR, coronary artery bypass grafting (CABG), surgical aortic valve replacement (SAVR), or CABG+SAVR according to *International Classification of Diseases, Tenth Revision* and current procedural technology codes between July 2016 and December 2018 were discharged alive, did not experience mortality within 30 days of discharge, and had continuous Medicare coverage for at least 6 months before the admission and 1 year post-discharge or until death were included.

Claims-Based Frailty Index

The primary exposure was the claims-based frailty index (CFI), which was calculated using a validated claims-based algorithm.^{22,23} The CFI assigns frailty status through the identified *International Classification of Diseases, Tenth Revision* and current procedural technology codes associated with a beneficiary.²⁴ The frequency of *International Classification of Diseases, Tenth Revision* and current procedural technology codes and the associated CFI weights are listed in Table S1. Beneficiaries were stratified into quartiles of CFI, with quartile 1 representing the lowest level of frailty and quartile 4 representing the highest level of frailty.

CR Use

CR use was extracted from the carrier and outpatient facility files as previously described.^{8,25} CR use was defined as attending at least 1 CR session within 1 year of discharge. In addition, time to first CR session, total CR sessions attended, and completion of all 36 recommended sessions were evaluated (all covariates were analyzed as conditional on any CR use).

Outcomes

The primary outcome was 1-year mortality, which was collected from the MBSF, and was defined as death occurring within 365 days of discharge.

Covariates

The MBSF, inpatient, and carrier files were queried for demographic, procedural, and outcome data, as in previous works.²⁶ Beneficiary home zip code was used to abstract additional geographic data including the distressed community index, a composite measure of local community distress, which is based on the American Community Survey. The distressed community index was calculated utilizing the Economic Innovation Group's Distressed Communities Index licensed data sets; covariates included in the distressed community index are rates of high school diploma education, poverty, employment, housing vacancy, median household income, change in employment, and change in local establishments. The findings expressed in this publication are solely those of the authors and not necessarily those of The Economic Innovation Group. The Economic Innovation Group does not guarantee the accuracy or reliability of, or necessarily agree with, the information provided herein.²⁷

Statistical Analysis

Patient risk factors, baseline demographic data, and CR use were compared between CFI quartiles. Categorical variables were tested for significant differences using the χ^2 and Fisher exact tests, and the Wilcoxon rank-sum test was used for continuous variables. Multivariable regression models were used to evaluate the association between frailty quartile and CR use measures, adjusting for patient, regional, and hospital factors. Multivariable logistic regression was used to evaluate binary outcomes (any CR use and completion of 36 sessions), and Poisson regression was used to evaluate count outcomes (days to first session and number of sessions attended).

Bivariate analysis of 1-year mortality and CFI strata was performed. Inverse probability treatment weighting (IPTW) was used to estimate the adjusted percentage of 1-year mortality for CR users and nonusers across quartiles of CFI and the difference in mortality between CR users and nonusers. Crude associations between CFI and various outcomes were tested using the Cochran-Armitage test of trend. Models were adjusted for patient, regional, and hospital factors. Probability weights for the likelihood of attending CR were estimated for each observation based on patient, regional, and hospital factors using logistic regression. The c-statistic for this model was 0.75, indicating moderate discriminatory ability. Interaction between CR, CFI, and 1-year mortality in our IPTW analysis was tested using a nonparametric Wald test, with 7 df. The estimated effect of CR on 1-year mortality was estimated using the inverse probability weighting approach, and the estimate

reflects the average treatment effect among the treated, which avoids making inferences on the effect of CR among individuals who did not use CR.²⁸ Effect in this context measures the magnitude of association and does not imply causality. The primary findings of the IPTW analysis were confirmed utilizing multivariable regression and propensity score-matched cohort matching on the same preoperative characteristics that were controlled for in the IPTW analysis. The robustness of our primary findings was further evaluated among open surgical and percutaneous procedures. Raw and weighted standardized differences and variance ratios for characteristics in the sample can be found in Table S2 for IPTW and Table S3 for propensity score matching. Statistical analyses were performed using Stata, version 18 (Stata Corp, College Station, TX).

RESULTS

A total of 501 049 beneficiaries underwent PCI, TAVR, CABG, SAVR, or CABG+SAVR during the study period. The most common procedure in the cohort was PCI (54.3%), followed by CABG (23.0%), TAVR (13.4%), CABG+SAVR (5.5%), and SAVR (3.9%; Figure S1A). The median CFI score for the cohort was 0.20 (interquartile range, 0.17–0.23) with a skewed right distribution (Figure S1B), which is similar to previously published cardiometabolic cohorts.²³ There were statistically significant, but not clinically meaningful, differences between preprocedural frailty among patients undergoing different interventions (Figure S1C). The frequency of diagnostic codes contributing to CFI scores is listed in Table S1.

Table 1 displays demographics before a procedure, stratified by CFI quartile. Patients in increasing CFI quartiles had higher incidences of demographics known to be associated with poor outcomes after cardiovascular procedures, including older age, female sex, being more likely to be from racial minorities, and having higher Charlson comorbidity indexes. Adjusted analyses confirmed independent associations of many baseline covariates with CFI, as listed in Table S4.

Frailty and CR

Overall CR use was 37.7%. Patients undergoing interventional procedures utilized CR at lower percentages than patients undergoing open surgical interventions (PCI: 30%, TAVR: 30%, CABG: 55%, SAVR: 56%, and CABG+SAVR: 52%; $P<0.001$). Increasing frailty was associated with decreased CR use (CFI Q1: 49.7% versus CFI Q4: 23.7%; Figure 1A). Days to first CR session increased with increasing CFI quartile (CFI Q1: 45 days versus CFI Q4: 62 days; Figure 1B). Completion of all recommended >36 CR sessions and average number of CR sessions completed both decreased with increasing frailty (completion of >36 sessions: CFI Q1: 31.3% versus CFI Q4: 23.6%; average number of sessions: CFI Q1: 26.6 versus CFI Q4: 23.1; Figure 1C and 1D). Multivariable

Table 1. Baseline Comorbidities by Claims-Based Frailty Quartile

Characteristic	Level	Overall sample	Claims-based frailty index quartile				P value
			Quartile 1 (least frail)	Quartile 2	Quartile 3	Quartile 4 (most frail)	
Sample size		501 049 (100.0%)	125 273 (25.0%)	125 246 (25.0%)	125 252 (25.0%)	125 278 (25.0%)	
Age, y; mean (SD)		75.9 (7.3)	74.7 (6.6)	75.8 (7.1)	76.3 (7.4)	76.7 (7.8)	<0.001
Female, n (%)		185 225 (37.0%)	27 216 (21.7%)	41 376 (33.0%)	52 300 (41.8%)	64 333 (51.4%)	<0.001
Race/ethnicity, n (%)	White	447 550 (89.3%)	113 430 (90.5%)	112 321 (89.7%)	111 294 (88.9%)	110 505 (88.2%)	<0.001
	Black	25 819 (5.2%)	4316 (3.4%)	5863 (4.7%)	7186 (5.7%)	8454 (6.7%)	
	Other race/ethnicity	6759 (1.3%)	1923 (1.5%)	1748 (1.4%)	1663 (1.3%)	1425 (1.1%)	
	Asian	6244 (1.2%)	1560 (1.2%)	1666 (1.3%)	1612 (1.3%)	1406 (1.1%)	
	Hispanic	5379 (1.1%)	1028 (0.8%)	1218 (1.0%)	1434 (1.1%)	1699 (1.4%)	
	North American native	2751 (0.5%)	432 (0.3%)	672 (0.5%)	770 (0.6%)	877 (0.7%)	
	Unknown	6547 (1.3%)	2584 (2.1%)	1758 (1.4%)	1293 (1.0%)	912 (0.7%)	
Dual eligible, n (%)		65 924 (13.2%)	7232 (5.8%)	11 895 (9.5%)	17 411 (13.9%)	29 386 (23.5%)	
Procedure type, n (%)	Isolated CABG	115 237 (23.0%)	34 069 (27.2%)	30 405 (24.3%)	28 502 (22.8%)	22 261 (17.8%)	<0.001
	Isolated SAVR	19 293 (3.9%)	6463 (5.2%)	5223 (4.2%)	4332 (3.5%)	3275 (2.6%)	
	CABG+SAVR	27 516 (5.5%)	12 189 (9.7%)	6750 (5.4%)	4984 (4.0%)	3593 (2.9%)	
	PCI	271 984 (54.3%)	57 102 (45.6%)	65 529 (52.3%)	70 574 (56.3%)	78 779 (62.9%)	
	TAVR	67 019 (13.4%)	15 450 (12.3%)	17 339 (13.8%)	16 860 (13.5%)	17 370 (13.9%)	
Elective admission, n (%)		186 679 (37.3%)	61 709 (49.3%)	49 462 (39.5%)	41 640 (33.2%)	33 868 (27.0%)	<0.001
Transferred patient, n (%)		74 881 (14.9%)	9897 (7.9%)	17 133 (13.7%)	22 360 (17.9%)	25 491 (20.3%)	<0.001
Hospital length of stay, d; mean (SD)		5.7 (5.7)	4.4 (3.5)	5.1 (4.7)	6.1 (5.9)	7.3 (7.3)	<0.001
Discharge to extended care facility, n (%)		98 869 (19.7%)	11 670 (9.3%)	17 841 (14.2%)	26 329 (21.0%)	43 029 (34.3%)	<0.001
Charlson comorbidity index, n (%)	None	41 593 (8.3%)	23 220 (18.5%)	10 537 (8.4%)	5 523 (4.4%)	2 313 (1.8%)	<0.001
	1–2	211 899 (42.3%)	75 831 (60.5%)	63 293 (50.5%)	45 827 (36.6%)	26 948 (21.5%)	
	3–4	129 310 (25.8%)	19 656 (15.7%)	33 117 (26.4%)	39 060 (31.2%)	37 477 (29.9%)	
	>5	118 247 (23.6%)	6566 (5.2%)	18 299 (14.6%)	34 842 (27.8%)	58 540 (46.7%)	
Distressed community index quintile, n (%)	First prosperous	121 383 (24.2%)	35 306 (28.2%)	30 862 (24.6%)	28 655 (22.9%)	26 560 (21.2%)	<0.001
	Second	109 753 (21.9%)	29 309 (23.4%)	27 758 (22.2%)	26 705 (21.3%)	25 981 (20.7%)	
	Third	98 728 (19.7%)	24 137 (19.3%)	24 893 (19.9%)	24 941 (19.9%)	24 757 (19.8%)	
	Fourth	92 853 (18.5%)	20 849 (16.6%)	22 754 (18.2%)	24 058 (19.2%)	25 192 (20.1%)	
	Fifth distressed	78 332 (15.6%)	15 672 (12.5%)	18 979 (15.2%)	20 893 (16.7%)	22 788 (18.2%)	
Census region, n (%)	Midwest	120 868 (24.1%)	29 907 (23.9%)	30 572 (24.4%)	30 225 (24.1%)	30 164 (24.1%)	<0.001
	Northeast	92 624 (18.5%)	23 077 (18.4%)	23 425 (18.7%)	23 366 (18.7%)	22 756 (18.2%)	
	South	205 487 (41.0%)	49 788 (39.7%)	50 508 (40.3%)	51 879 (41.4%)	53 312 (42.6%)	
	West	82 070 (16.4%)	22 501 (18.0%)	20 741 (16.6%)	19 782 (15.8%)	19 046 (15.2%)	
Urbanicity, n (%)	Urban	84 345 (16.8%)	20 671 (16.5%)	20 341 (16.2%)	20 731 (16.6%)	22 602 (18.0%)	<0.001
	Suburban	186 217 (37.2%)	48 070 (38.4%)	46 587 (37.2%)	45 882 (36.6%)	45 678 (36.5%)	
	Small town	117 790 (23.5%)	28 953 (23.1%)	29 500 (23.6%)	29 824 (23.8%)	29 513 (23.6%)	
	Rural	112 697 (22.5%)	27 579 (22.0%)	28 818 (23.0%)	28 815 (23.0%)	27 485 (21.9%)	
Distance to nearest cardiac rehabilitation facility, n (%)	Within the zip code	118 642 (23.7%)	29 358 (23.4%)	29 470 (23.5%)	29 659 (23.7%)	30 155 (24.1%)	<0.001
	1–15 miles	253 442 (50.6%)	64 165 (51.2%)	62 975 (50.3%)	62 883 (50.2%)	63 419 (50.6%)	
	16–30 miles	90 656 (18.1%)	22 666 (18.1%)	23 049 (18.4%)	22 888 (18.3%)	22 053 (17.6%)	

(Continued)

Table 1. Continued

Characteristic	Level	Overall sample	Claims-based frailty index quartile				P value
			Quartile 1 (least frail)	Quartile 2	Quartile 3	Quartile 4 (most frail)	
	>30 miles	38 309 (7.6%)	9084 (7.3%)	9752 (7.8%)	9822 (7.8%)	9651 (7.7%)	
Hospital teaching status, n (%)	Major	134 845 (26.9%)	33 113 (26.4%)	33 537 (26.8%)	33 891 (27.1%)	34 304 (27.4%)	<0.001
	Minor	272 274 (54.3%)	68 183 (54.4%)	68 126 (54.4%)	68 204 (54.5%)	67 761 (54.1%)	
	Nonteaching	93 930 (18.7%)	23 977 (19.1%)	23 583 (18.8%)	23 157 (18.5%)	23 213 (18.5%)	
System-affiliated hospital, n (%)		418 306 (83.5%)	104 282 (83.2%)	104 430 (83.4%)	104 592 (83.5%)	105 002 (83.8%)	0.001
Hospital ownership	Not-for-profit	385 956 (77.0%)	97 276 (77.7%)	96 791 (77.3%)	96 187 (76.8%)	95 702 (76.4%)	<0.001
	For-profit	73 490 (14.7%)	17 579 (14.0%)	18 185 (14.5%)	18 702 (14.9%)	19 024 (15.2%)	
	Government	41 603 (8.3%)	10 418 (8.3%)	10 270 (8.2%)	10 363 (8.3%)	10 552 (8.4%)	
Hospital bed size	>500	191 083 (38.1%)	47 433 (37.9%)	47 875 (38.2%)	47 791 (38.2%)	47 984 (38.3%)	<0.001
	300–500	146 015 (29.1%)	35 981 (28.7%)	36 124 (28.8%)	36 884 (29.4%)	37 026 (29.6%)	
	100–300	143 808 (28.7%)	36 890 (29.4%)	36 049 (28.8%)	35 428 (28.3%)	35 441 (28.3%)	
	<100	20 143 (4.0%)	4969 (4.0%)	5198 (4.2%)	5149 (4.1%)	4827 (3.9%)	

Claims-based frailty quartile ranges: quartile 1: 0–0.170; quartile 2: 0.170–0.197; quartile 3: 0.197–0.230; and quartile 4: 0.230–0.470. CABG indicates coronary artery bypass grafting; PCI, percutaneous coronary intervention; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.

analysis identified that higher frailty quartiles had lower adjusted CR use (adjusted odds ratio_{CFI-Q4 versus CFI-Q1}, 0.63; $P<0.001$) and lower likelihood of completing all CR sessions (adjusted odds ratio_{CFI-Q4 versus CFI-Q1}, 0.71; $P<0.001$), completed fewer sessions overall (difference in sessions_{CFI-Q4 versus CFI-Q1}, 0.896; $P<0.001$), and had more days elapsed from discharge to first session (difference in days_{CFI-Q4 versus CFI-Q1}, 1.17 $P<0.001$; Table 2).

Frailty, CR, and Outcomes

Increasing frailty quartile was associated with increased 1-year mortality (CFI Q1: 2.5% and CFI Q4: 16.9%; $P<0.001$; Figure 2A). One-year mortality was higher among CR nonusers compared with CR users (11.9% versus 2.6%; $P<0.001$). Patients in higher CFI quartiles had a larger associated reduction in 1-year mortality from attending CR, as opposed to patients in lower CFI quartiles (CFI Q1: 2.7% reduction for CR users compared with nonusers and CFI Q4: 14.3% reduction for CR users versus nonusers; $P<0.001$; Figure 2B). There was a significant interaction between CFI, CR use, and 1-year mortality in the IPTW model ($P<0.001$). Kaplan-Meier analyses showed a consistent divergence of mortality curves over time, regardless of CFI quartile (Figure S2). IPTW-adjusted outcomes confirmed an increased effect size of reduced 1-year mortality in CR users in frailer CFI quartiles (reduction in mortality: IPTW-adjusted: Q1: 1.7%, Q4: 9.2%; $P<0.001$; Table 3). Multivariable analysis and propensity score matching confirmed the findings in the IPTW analysis (Table S5). The primary findings were robust when evaluated separately for open surgical and percutaneous procedural cohorts (Table S6).

DISCUSSION

This large, nation-wide study is the first to investigate the association between frailty, CR use, and outcomes in a procedural cohort and has revealed several findings. First, frail patients were less likely to attend CR; the least frail patients in our cohort attended any CR session nearly twice as frequently as the frailest patients. Furthermore, frail patients took longer to enroll in CR and were less likely to complete all sessions after starting CR. Most importantly, findings from this study demonstrate that CR use conferred a nearly 5 times higher associated reduction in 1-year mortality among frail patients compared with nonfrail patients, suggesting that frail patients derive greater benefit from CR despite lower usage.

Frail patients were investigated because there are differing opinions on whether or not physically frail patients are (1) safe to attend CR²⁹ and (2) able to improve physical function through targeted exercise therapy.^{13,30} This study, combined with the existing literature, suggests that frail patients do, in fact, stand to benefit more than nonfrail patients from CR attendance, and CR is underutilized in this group. Studies investigating CR referral patterns have found that while most patients receive CR referral orders,^{31,32} older and frailer patients are less likely to receive CR referrals,³³ and physician bias and attitudes to CR are a driver of overall CR enrollment.^{34–36} Qualitative studies aimed at understanding the underlying reasons for CR nonreferral and CR nonattendance are needed to design targeted interventions to increase overall CR participation. This study argues that preprocedural expectation setting should include discussing CR attendance, with an extensive discussion of the benefits



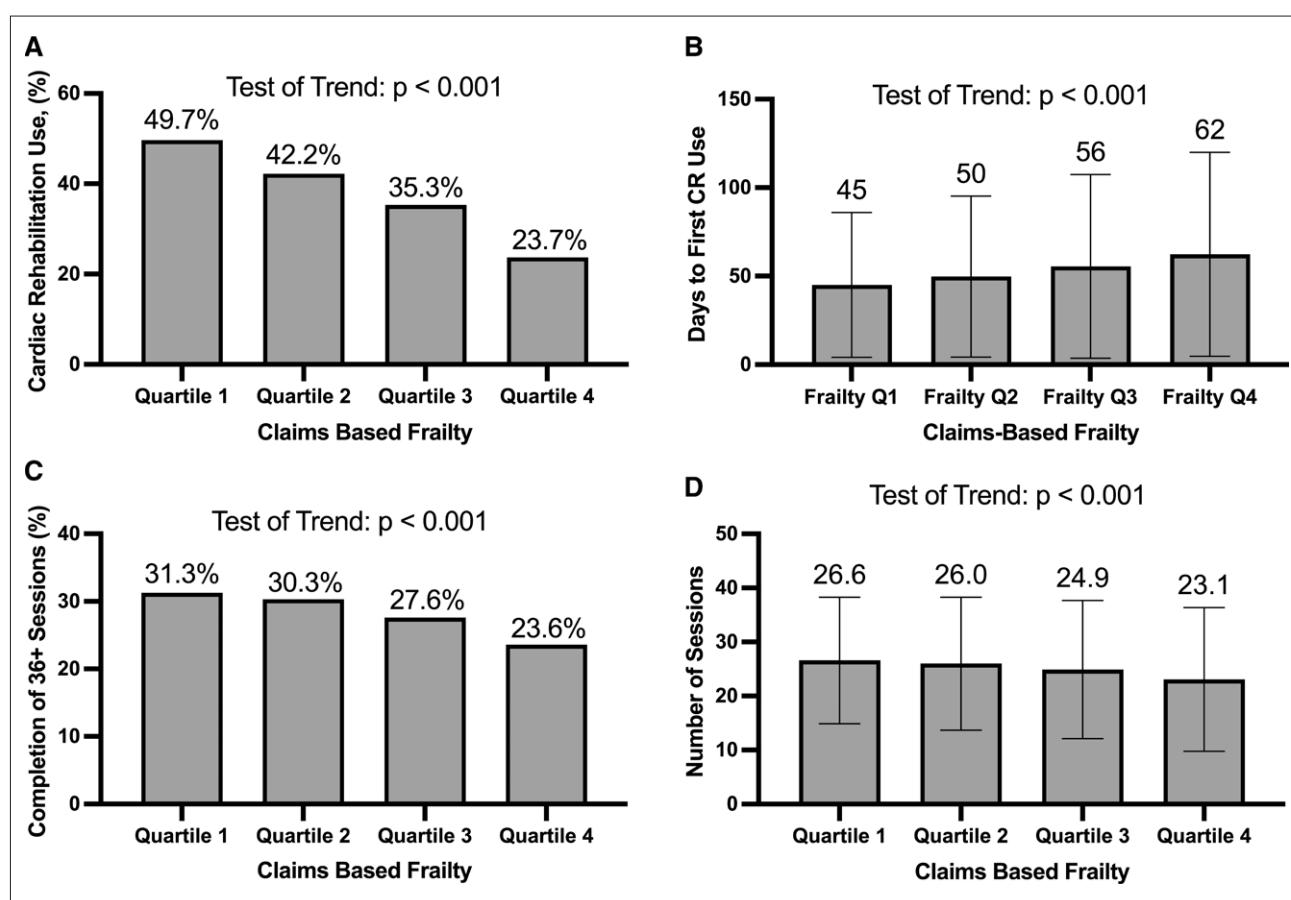


Figure 1. Crude cardiac rehabilitation use stratified by claims-based frailty quartile.

A, Any cardiac rehabilitation use. **B**, Days to first cardiac rehabilitation use. **C**, Completion of all recommended sessions, conditional on any cardiac rehabilitation use. **D**, Total number of sessions, conditional on any cardiac rehabilitation use. Error bars represent SD.

of CR in patients who seem frail. Furthermore, in the present cohort, frail patients not only have lower overall CR enrollment, but those who do enroll in CR complete fewer CR sessions on average and are less likely to complete the guideline-recommended 36 sessions. Completing fewer sessions of CR has been associated with higher rates of cardiovascular events and death,³⁷ and there is a documented dose-effect curve between CR sessions attended and reduction in mortality.³² It is clear that attendance at any CR session is not a sufficient end point for studying CR use, and maximizing the number of CR

sessions that patients attend likely improves outcomes. Previous research has suggested that frail patients may be less likely to complete all required sessions of CR at least in part due to the inability to complete traditional CR exercise regimens.³⁸ Flint et al¹² have recommended extensive adaptations of traditional CR interventions to better serve frail patients, such as modified strength regimens, fall mitigation training by a physical therapist, and the close involvement of a clinical physiologist, which can appropriately tailor exercise and intensity on an individual basis. Modifications to CR programs should be made to

Table 2. Multivariable Logistic and Poisson Regression of Cardiac Rehabilitation Use by Claims-Based Frailty Quartile

Claims-based frailty quartile	Any use (odds ratio [95% CI])	Days to first session (Diff [95% CI])	No. of sessions (Diff [95% CI])	Cardiac rehabilitation completion (odds ratio [95% CI])
Quartile 1 (least frail)	Ref	Ref	Ref	Ref
Quartile 2	0.93 (0.91–0.94)	1.05 (1.04–1.06)	0.990 (0.985–0.995)	0.97 (0.95–0.99)
Quartile 3	0.84 (0.82–0.85)	1.11 (1.10–1.12)	0.957 (0.951–0.963)	0.86 (0.84–0.89)
Quartile 4 (most frail)	0.63 (0.62–0.64)	1.17 (1.16–1.19)	0.896 (0.889–0.903)	0.71 (0.69–0.74)

Adjusted for patient age, sex, race/ethnicity, dual-eligible status, procedure type, transfer status, elective vs nonelective admission, index length of stay, discharge to home vs not home, Charlson comorbidity index, distance to nearest cardiac rehabilitation facility, index hospital bed size and teaching status, US census region, and distressed community index quintile.

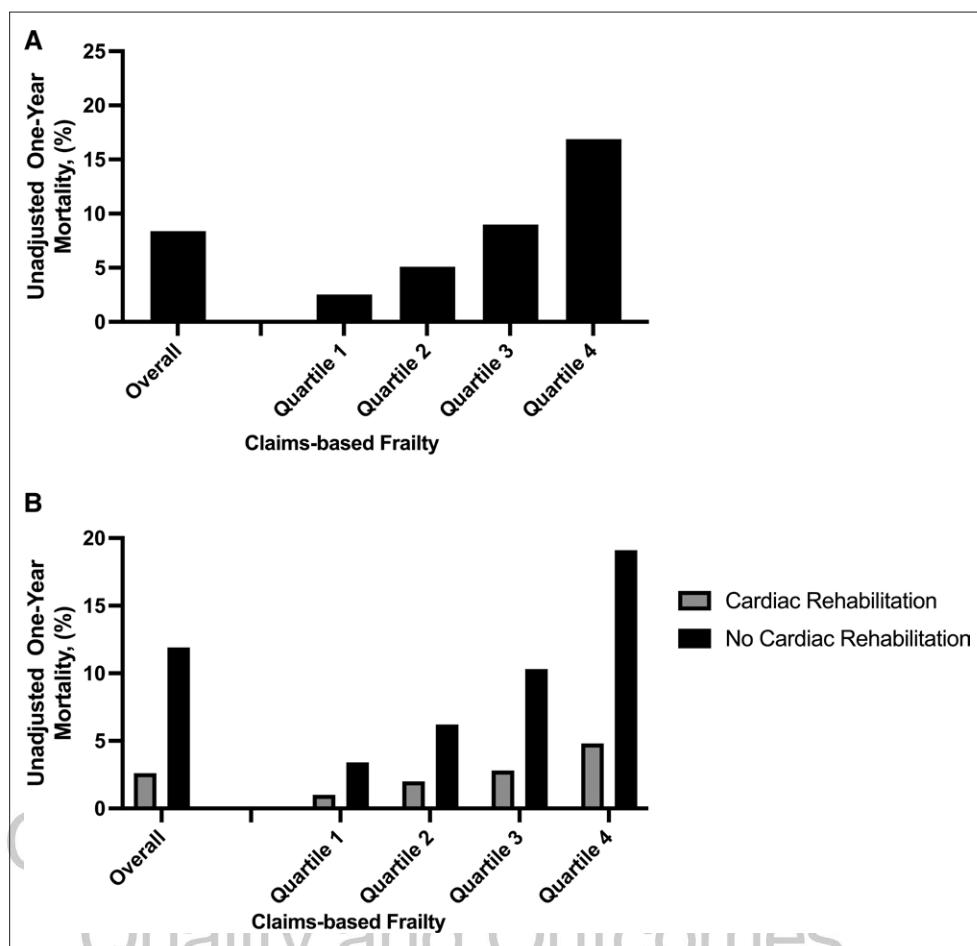


Figure 2. Unadjusted 1-year mortality.

A, Stratified by claims-based frailty quartile. **B**, Stratified by frailty quartile and cardiac rehabilitation use.

address the needs of frail patients to decrease dropout rates, and there is a need for qualitative studies to further understand the reasons for higher dropout rates in this population.

Despite lower CR use and adherence, it appears that more frail patients benefit more from CR compared with less frail individuals. There was nearly a 10-percentage point reduction in 1-year mortality associated with CR users in the frailest CFI quartile, as opposed to only a 2-percentage point reduction in those who were in the least frail quartile. Furthermore, patients in the highest frailty quartile who complete CR have adjusted 1-year mortality rates similar to CR nonusers in the least frail quartile. The higher efficacy of CR in reducing 1-year mortality that is observed in frail patients may be due to a myriad of factors, including increased cardiovascular function, improved ability to perform activities of daily living, positive psychological effects of socialization and exercise, or a direct effect on improved cardiovascular metrics.^{10,13,14} Existing literature suggests that current CR infrastructure cannot support all patients eligible for CR, and therefore, it is important to prioritize patients who stand to benefit the most from CR use.³⁹ While efforts

to expand outpatient CR programs to provide slots for all eligible patients should be continued, this study argues that frail patients are a subgroup that should be prioritized for CR referrals and enrollment.

Many indices of frailty exist, with none being heralded as the gold standard. We utilized an index of frailty that leverages the *International Classification of Diseases, Tenth Revision* and current procedural technology codes that have been correlated and weighted against a 56-point frailty index.^{22,23} The present cardiac procedural cohort has a median CFI of 0.20, which is similar to previous cohorts of Medicare patients with cardiometabolic disease.^{23,40} The agreement of CFI with a variety of previous frailty indices has been verified, and CFI scores above 0.21 to 0.24 correlate with what survey-based frailty indices identify as frail.⁴¹ Based on these cutoffs, the majority of patients included in Q3 and all patients in Q4 in the current study would be considered frail. Studying frailty in large clinical data sets remains difficult, given that most cardiovascular procedural cohorts do not collect any direct metric of frailty. CFI may be a useful evaluation of frailty because it calculates frailty from diagnosis and procedural codes that

Table 3. Absolute and Absolute Differences in Crude and Inverse Probability Treatment Weighting Adjusted 1-Year Mortality by Frailty and CR Use

	Unadjusted			Inverse probability treatment weighting		
	CR users	Non-CR users	Absolute difference	CR users	Non-CR users	Absolute difference
Overall	2.6%	11.9%	-9.3% (-9.4% to -9.2%)	2.6%	7.4%	-4.8% (-4.9% to -4.7%)
Frailty quartile 1 (least frail)	1.0%	3.4%	-2.7% (-2.8% to -2.5%)	2.7%	1.0%	-1.7% (-1.9% to -1.5%)
Frailty quartile 2	2.0%	6.2%	4.3% (-4.5% to -4.0%)	1.9%	4.7%	-2.8% (-3.0% to -2.5%)
Frailty quartile 3	2.8%	10.3%	-7.4% (-7.7% to -7.2%)	2.9%	8.0%	-5.1% (-5.4% to -4.9%)
Frailty quartile 4 (most frail)	4.8%	19.1%	-14.3% (-14.6% to -14.0%)	4.8%	14.0%	-9.2% (-9.5% to -8.9%)

CR indicates cardiac rehabilitation.

likely exist in most claims-based data sets or are easily merged to existing clinical data sets. Further work is needed to determine if there is CFI score can be used as a clinical indicator for increased risk of poor outcomes beyond mortality in cardiovascular cohorts, such as extended length of stay and nonfatal postoperative complications.

Limitations

This study has limitations that should be considered. First, this study is limited to patients undergoing percutaneous or open surgical revascularization or aortic valve replacement, and as such, its findings may not be generalizable to patients eligible for CR for other reasons (mitral valve replacement, heart failure, and so on). This study does include the 4 highest volume procedure types that qualify patients for CR, and therefore, we think that it is likely representative of all patients undergoing procedures that qualify for CR.⁸ Furthermore, this study was limited to beneficiaries enrolled in Medicare fee-for-service; therefore, the study findings may not be generalizable to younger patient populations or those insured under Medicare Advantage or commercial insurance. This investigation did not have access to CR referral rates, and it is possible that subjectively frail patients were not referred to CR; however, previous investigations have found that hospital-level factors are far more important than patient-level factors in explaining CR referral percentages.⁴² This study used the most common end points for evaluating CR use, such as any CR attendance, CR completion, number of CR sessions completed, and time to first CR use, although there may exist other CR metrics that are associated with outcomes (duration of CR use, physiological improvements during CR, and so on).^{8,25,43} Additional physiological metrics from CR and more detailed information about CR sessions are not available in the MBSF, and to date, none of these end points is proven to have additional utility over the traditional CR metrics utilized in this study. Furthermore, while we use multivariable and IPTW to control for observed

differences between CR users and nonusers, residual confounding may persist (eg, cardiovascular or physical function, social support, and availability of transportation). Propensity score matching was used to advance the balancing of covariates. CFI, while validated against a survey-based index of frailty on a population level, may not accurately predict frailty immediately following surgical interventions or in other specialized cases; however, it remains the most robust assessment of frailty in claims-based data. While CFI has been validated against 9 well-known clinical assessments of frailty, these findings have not been validated in additional cohorts.⁴¹ Another limitation of the current study is that the MBSF does not capture which patients are offered CR referrals, and future work should seek to better understand the association between frailty and CR referrals. While this study did control for discharge location (either to home or extended care facility), given its known association with CR use and mortality,⁴⁴ further evaluation is warranted to evaluate the relationship between postdischarge interventions and their relationship with CFI, CR use, and 1-year mortality. Previous data suggest that hospital- and provider-level variations persist beyond patient-level factors, and future studies should seek to understand the underlying reasons for CR nonreferral.³⁵ Recent establishment of CR referral quality metrics for post-PCI patients by the European Society of Cardiology will likely advance this work by tracking and reviewing referral patterns.⁴⁵ Finally, this study did not include clinician factors, such as time in practice and subspecialization, as well as individual clinician attitudes towards CR, which could explain some of the variation in CR use.³³

Conclusions

In this large database analysis of Medicare beneficiaries undergoing both interventional and open surgical cardiac procedures, frailty was associated with lower CR use despite greater associated reductions in 1-year mortality. Targeted quality improvement projects locally and nationally aimed at increasing CR enrollment in frail patients

may increase overall CR use and improve outcomes among patients undergoing cardiovascular interventions.

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Supplemental Material

Tables S1–S6

Figures S1–S2

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