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ORIGINAL RESEARCH

OUTCOMES AND QUALITY

Predictors and Variation in Cardiac Rehabilitation Participation After Transcatheter Aortic Valve Replacement

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ABSTRACT

BACKGROUND Cardiac rehabilitation (CR) is strongly recommended for a spectrum of cardiovascular conditions and procedures including aortic valve replacement.

OBJECTIVES The purpose of this study was to characterize patient and hospital factors associated with CR participation after transcatheter aortic valve replacement (TAVR) and determine which factors explain hospital-level variation in CR participation.

METHODS We linked clinical and administrative claims data from patients who underwent TAVR at 24 Michigan hospitals between January 1, 2016 and June 30, 2020 and obtained rates of CR enrollment within 90 days of discharge. Sequential mixed models were fit to evaluate hospital variation in 90-day post-TAVR CR participation.

RESULTS Among 3,372 patients, 30.6% participated in CR within 90-days after discharge. Several patient factors were negatively associated with CR participation after TAVR including older age, Medicaid insurance, atrial fibrillation/flutter, dialysis use, and slower baseline 5-m walk times. There was substantial hospital variation in CR participation after TAVR ranging from 5% to 60% across 24 hospitals. Patient case mix did not explain hospital variation in CR across hospitals with median OR numerically increasing from 2.11 (95% CI: 1.62-2.67) to 2.13 (95% CI: 1.61-2.68) after accounting for patient-level factors.

CONCLUSIONS Less than 1 in 3 patients who underwent TAVR in Michigan participated in CR within 90-days of discharge. Although several patient factors are associated with CR participation, hospital-level variation in CR participation after TAVR is not explained by patient case mix. Identifying hospital processes of care that promote CR participation after TAVR will be critical to improving CR participation after TAVR. (JACC Adv 2023;2:100581) Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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ABBREVIATIONS AND ACRONYMS

aOR = adjusted odds ratio

CR = cardiac rehabilitation

HCAHPS = Hospital Consumer Assessment of Healthcare Providers and Systems

ICC = intraclass correlation coefficient

MOR = median odds ratio

MVC = Michigan Value Collaborative

PCI = percutaneous coronary intervention

SAVR = surgical aortic valve replacement

TAVR = transcatheter aortic valve replacement

Cardiac rehabilitation (CR) is strongly recommended in international guidelines for a spectrum of cardiovascular conditions and procedures including coronary artery disease, percutaneous coronary intervention (PCI), and coronary artery bypass graft surgery[1-3] where studies have demonstrated that CR is associated with lower mortality and readmissions and higher quality of life.[4-6] CR is recommended and covered by insurance for patients who have undergone heart valve repair or replacement including transcatheter aortic valve replacement (TAVR).[7] Expert consensus in 2017 recommended that post-TAVR care and long-term management, similar to surgical aortic valve replacement (SAVR), should include CR.[8]

With the emergence of TAVR as the dominant treatment for aortic stenosis in the United States, there has been dramatic improvement in the safety of the procedure through the development of new devices and techniques over the past decade. However, there is a dearth of research evaluating overall and hospital-level rates of CR use after TAVR. Moreover, patients undergoing TAVR tend to be older and have multiple comorbidities compared with patients undergoing other cardiovascular procedures, and patient- and hospital-level factors associated with CR use may be unique to this population.[9,10] We sought to evaluate the association between patient demographic, socioeconomic, and clinical factors with CR participation after TAVR. The identification of important patient and hospital factors associated with CR use after TAVR will help design and target strategies to improve CR use.

METHODS

DATA SOURCES. We linked 2 data sources for this study. The first was the Michigan Structural Heart Consortium clinical TAVR registry, which includes all patients who underwent TAVR at 24 nonfederal PCI-capable hospitals in Michigan. The registry is based on the transcatheter valve therapy TAVR platform[11] and enhanced by rigorous auditing practices.

The second data source was derived from the Michigan Value Collaborative (MVC) which developed and maintains a validated claims-based registry with 90-day episodes of care from Medicare fee-for-service and both commercial and Medicare Advantage administrative claims from Blue Cross Blue Shield of Michigan preferred provider organization and Blue Care Network Health Maintenance Organization.[12] All clinically-related claims within 90 days after discharge from the index hospitalization or procedure were included in the episode. As part of the MVC episode creation algorithm, a patient cannot be in more than 1 90-day episode of care at a time. For instance, a patient who underwent PCI 4 weeks before TAVR would have a 90-day episode of care initiated for PCI but not for TAVR given that the TAVR occurred within the 90-day episode of care for PCI.

STUDY POPULATION. We evaluated all TAVRs that occurred at 24 hospitals between January 1, 2016 and June 30, 2020. To link records between 2 data sources that do not share a unique key, we used a multiple valued logic approach to matching, also known as fuzzy matching.[13] Further details of the fuzzy matching algorithm are described in the Supplemental Methods.

Hospital-level patient satisfaction scores from the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey were also linked to the data.[14] Ten items related to perceptions of physician communication, facility cleanliness, and overall hospital satisfaction were included, and a principal components analysis was performed to reduce multicollinearity. The first 2 principal components were retained, with the first principal component explaining 60.1% of the total variance and the second explaining an additional 16.6% (76.7% total). Based on the loadings, the first principal component is a broad summary of all 10 items (Supplemental Table 1), whereas the second principal component had the highest loadings for questions related to cleanliness and room noise. Lower scores on each principal component indicate higher patient perceptions of hospital quality.

OUTCOMES. CR participation was defined as ≥1 facility or professional administrative claim for outpatient CR within 90 days following discharge based on current procedural terminology codes (93,797 and 93,798), health care common procedure coding system codes (G0422 and G0423), and revenue center code 943.[15]

STATISTICAL ANALYSIS. Descriptive statistics in the form of frequencies and percentages (categorical variables) or mean ± SD (interval variables) are provided for patient CR participation, demographics, and clinical characteristics. Patient-level variables include the 12-item Kansas City Cardiomyopathy Questionnaire overall score,[16,17] an indicator of health status, and the 5-m walk test,[9,10,18] a measure of frailty in individuals who are candidates for cardiac surgery.

Unadjusted differences in demographics and comorbidities are assessed using chi-square tests or *t*-tests, depending on the variable type.

The adjusted analysis consists of a series of mixed effects logistic regression models. The first model contains only a random effect for hospital and fixed effects for discharge year. The second model adds patient demographic, socioeconomic, and clinical variables (Supplemental Table 2), and the final model incorporates the 2 principal components based on the HCAHPS hospital-level data. See Supplemental Methods for a detailed description of specific variables including the Distressed Communities Index, calculation of distance to nearest CR site, and how missing data were handled. Continuous variables were standardized to have a zero mean and unit variance, and the corresponding odds ratios represent the expected change in the odds of CR participation for a 1 standard deviation increase in the respective predictor.

Fixed effect and variance component estimates are provided for each model along with median odds ratios (MORs) and intraclass correlation coefficients (ICCs). MORs are a measure of variability between clusters in the likelihood of CR participation between 2 randomly selected hospitals for a patient that is otherwise identical. ICCs are a summary of how much variability in the outcome can be attributed to hospital-level factors rather than patient-level factors. For MORs and ICCs, 95% CIs are provided based on percentiles from 500 bootstrap replicates.

We performed 2 sensitivity analyses. First, patients who experienced post-TAVR complications such as stroke may have been more likely to be discharged to a skilled nursing facility or in-patient rehabilitation center and thus would not have been included in the primary cohort. Therefore, we evaluated the association between factors included in the full final model among all patients discharged alive, regardless of discharge location. Second, using the same final full model specification, we excluded patients who underwent TAVR after February 29, 2020, to evaluate whether the same clinical factors were associated with CR use after excluding patients who may have been exposed to the dramatic changes in health care delivery related to the onset of the COVID-19 pandemic.

All analyses were performed using R version 4.1.3.[19] The University of Michigan Institutional Review Board approved the study and determined that it met the definition of research not requiring informed consent.

RESULTS

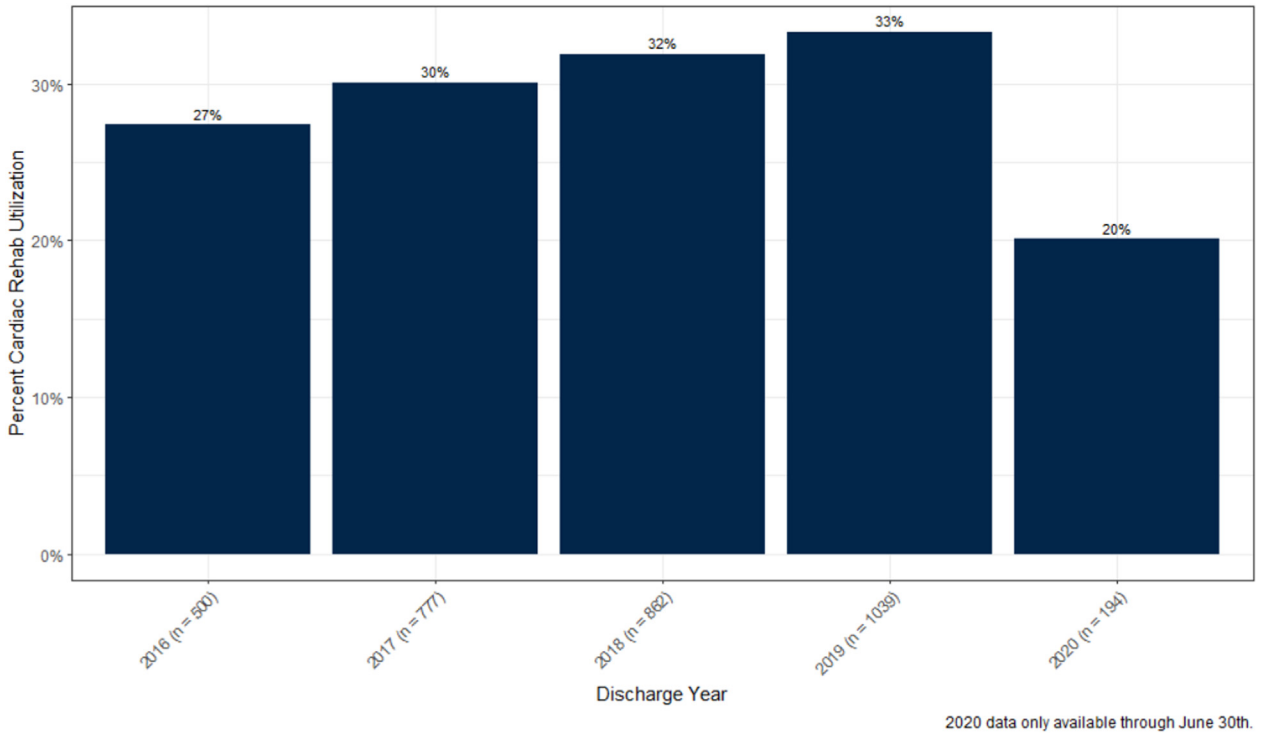
Of 4,405 MVC TAVR episodes from January 2, 2016, through August 27, 2020, 3,794 linkages with the TAVR clinical registry data were made. After excluding patients who either died in the hospital or were discharged to a location other than home (ie, hospice, skilled nursing facility, etc.), there were 3,372 patients in the CR study cohort (Supplemental Figure 1). The overall rate of 90-day CR participation after TAVR discharge was 30.6% and increased from 27% in 2016 to 33% in 2019 before dropping to 20% through the first two-quarters of 2020, coinciding with the onset of the COVID-19 pandemic (**Figure 1**).

Those who attended CR after TAVR were more likely to be younger, White, nonsmokers, and not having Medicaid insurance (ie, dual-eligible patients) (**Table 1**). In general, patients with lower Society of Thoracic Surgery predicted risk of mortality scores, higher baseline 12-item Kansas City Cardiomyopathy Questionnaire overall scores, and faster baseline 5-m walk times had higher rates of CR participation after TAVR (**Figure 2**).

FACTORS ASSOCIATED WITH CR PARTICIPATION. In the full multivariable logistic regression model, several patient and hospital factors were associated with CR participation after TAVR (Supplemental Tables 2 and 3). Patient demographic and socioeconomic factors including older age (adjusted odds ratio [aOR]: 0.80; 95% CI: 0.73-0.88), Medicaid insurance coverage (aOR: 0.47; 95% CI: 0.29-0.76), current dialysis (aOR: 0.54; 95% CI: 0.33-0.89), smoking (aOR: 0.42; 95% CI: 0.29-0.60), atrial fibrillation/flutter (aOR: 0.71; 95% CI: 0.59-0.85), and slower 5-m walk times (aOR: 0.85; 95% CI: 0.77-0.94) were independently associated with decreased odds of participating in CR after TAVR (**Central Illustration**). Higher baseline hemoglobin levels were associated with higher odds of CR enrollment (aOR: 1.11; 95% CI: 1.02-1.22). CR enrollment was also significantly lower in 2020 compared to the baseline year of 2016 (aOR: 0.47; 95% CI: 0.30-0.75). Notably, Distressed Communities Index scores, a measure of ZIP-code level socioeconomic distress, were not significantly associated with downstream CR use (**Figure 3**). Postprocedural in-hospital complications such as stroke, pacemaker implantation, and vascular complications were not significantly associated with postdischarge CR participation (**Figure 3**).

Inclusion of 2 principal components of hospital quality derived from hospital HCAHPS patient survey

FIGURE 1 Yearly Rates of 90-Day CR Participation After TAVR: 2016 to Quarter 2 of 2020



CR = cardiac rehabilitation; TAVR = transcatheter aortic valve replacement.

scores, we found that the first principal component, which had similar weightings for the results of all 10 HCAHPS survey questions, was significantly associated with CR enrollment. A change of 1 standard deviation in patient-perceived hospital quality, where higher values indicate lower quality assessments, is associated with a 31.5% decrease in the odds of attending CR.

In a sensitivity analysis including all patients discharged alive, regardless of discharge location, among 3,794 TAVR episodes, 1,083 (28.5%) participated in CR. Similar factors as noted in the full regression model from the primary analysis were associated with CR participation. However, 2 additional variables were also significantly associated with lower odds of CR participation including cardiac arrest within 24 hours of the procedure (aOR: 0.49; 95% CI: 0.25-0.95) and postprocedure stroke (aOR: 0.36; 95% CI: 0.16-0.79) (Supplemental Table 4). Second, after restricting the cohort to patients discharged before February 29, 2020 (the start of the COVID-19 pandemic), similar factors were associated with CR participation as compared with the findings from the primary analysis (Supplemental Table 4).

VARIATION IN CR PARTICIPATION BY HOSPITAL. The rate of CR participation within 90 days after TAVR varied from 5% to 60% across the 24 hospitals during the study period (**Central Illustration**). In Model 1, which included a hospital random intercept and discharge year, the hospital MOR was 2.11 (95% CI: 1.62-2.67) and the ICC was 16% (95% CI: 7%-24%). In Model 2, after including all patient-level covariates in the model, the hospital MOR was 2.13 (95% CI: 1.61-2.68) and the ICC was 16% (95% CI: 7%-25%). Put another way, adjusting for differences in patient case mix did not substantially explain the variation in CR enrollment across sites. Finally, adjusting for hospital quality by adding the 2 hospital quality principal components derived from the hospital HCAHPS survey results to the hierarchical regression reduced the MOR to 1.90 (95% CI: 1.46-2.28) and the ICC to 12% (95% CI: 5%-19%), explaining approximately 26% of the variance as compared with Model 1 (**Table 2**). There were no substantial differences in hospital bed size, teaching status, and HCAHPS

star rating between the 12 highest and 12 lowest hospitals when stratified by their 90-day post-TAVR CR participation rates (Supplemental Table 5).

DISCUSSION

In a diverse group of 24 hospitals that provide TAVR services in Michigan, our study revealed 3 major findings. First, <1 in 3 patients who undergo TAVR, and are discharged home, attend at least 1 session of CR within 90 days after discharge, highlighting a large quality gap.[20] Second, the following patient characteristics are significantly associated with CR participation: age, smoking status, dialysis, atrial fibrillation/atrial flutter, 5-m walk times, pre-procedure hemoglobin levels, and Medicaid insurance status. Hospital characteristics associated with hospital quality, as measured by patient survey, are also associated with CR use after TAVR. Notably, in-hospital complications after TAVR such as stroke, pacemaker implantation, and vascular complications were not significantly associated with CR participation. Third, there was substantial variation in rates of CR participation after TAVR across hospitals. This variation persisted after accounting for differences in patient case mix across sites and was attenuated when accounting for patient-reported measures of hospital quality. Taken together, this finding suggests that variation in CR participation after TAVR is not due to significant differences in measured patient case mix but may be related to differences in hospital quality and processes of care—2 important targets for future interventions to improve CR participation after TAVR.

We report a CR participation rate within 90 days after TAVR of 30.6%, which is modestly higher than other contemporary estimates which tended to rely exclusively on Medicare claims, whereas our study includes some younger commercially insured patients. This participation rate is far below the goal of increasing CR participation to 70% as suggested by the Million Hearts Cardiac Rehabilitation Collaborative.[20] Recently, Keteyian et al[21] reported that 26.4% of Medicare beneficiaries aged ≥65 years who underwent TAVR in 2017 attended at least 1 session of CR within 90 days after their qualifying event. When expanding the lookout period from 90 days to 365 days, the authors observed that only 29.7% of patients who underwent TAVR attended at least 1 session of CR. By comparison, 1-year rates of CR participation after isolated SAVR among Medicare beneficiaries were 44.7% in 2014.[22] Indeed, CR

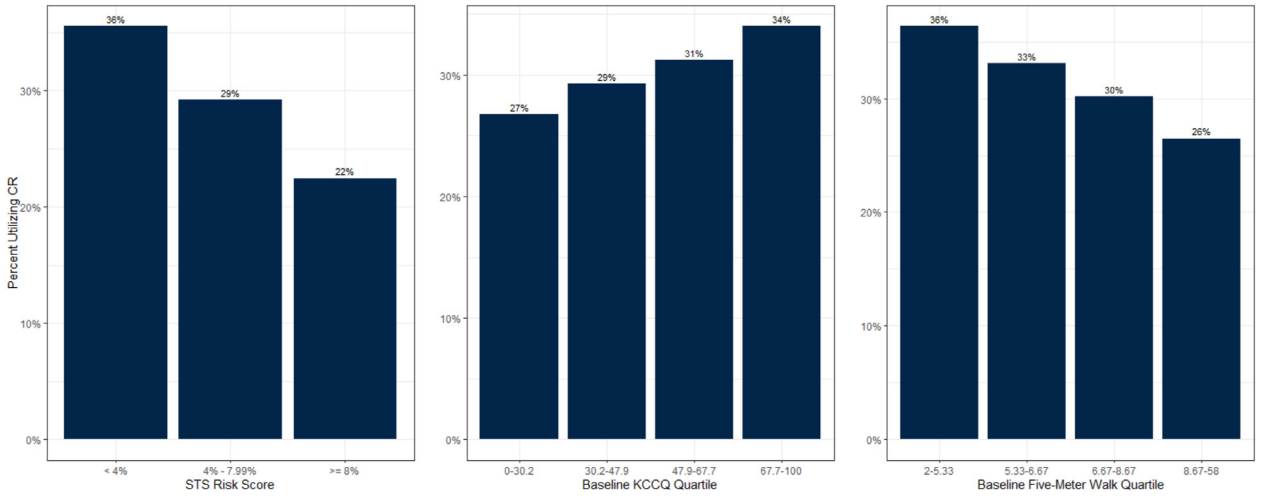
TABLE 1 Baseline Characteristics by CR Participation Within 90 Days After TAVR Discharge

	Cardiac Rehabilitation Participation (n = 1,031)	No Cardiac Rehabilitation Participation (n = 2,341)	*P* Value
Discharge year			0.002
2016	137 (13.29%)	363 (15.51%)	
2017	234 (22.7%)	543 (23.2%)	
2018	275 (26.67%)	587 (25.07%)	
2019	346 (33.56%)	693 (29.6%)	
2020	39 (3.78%)	155 (6.62%)	
Age, y	78.15 ± 8.35	79.86 ± 8.58	<0.001
Sex			0.092
Female	454 (44.03%)	1,106 (47.24%)	
Race			0.049
Black	31 (3.01%)	105 (4.49%)	
Other	15 (1.45%)	21 (0.9%)	
White	985 (95.54%)	2,215 (94.62%)	
Primary insurance coverage			0.079
Commercial	103 (9.99%)	189 (8.07%)	
Medicare	928 (90.01%)	2,152 (91.93%)	
Medicaid coverage (ie, dual-eligible patients)	25 (2.42%)	118 (5.04%)	<0.001
STS risk score	4.01 (2.76-6.07)	4.7 (3.1-7.2)	<0.001
Home oxygen	78 (7.57%)	204 (8.72%)	0.296
Current dialysis	26 (2.52%)	105 (4.49%)	0.009
Preprocedure hemoglobin	12.7 (11.4-13.8)	12.3 (11.1-13.5)	<0.001
Prior stroke/TIA	175 (17.02%)	401 (17.17%)	0.955
Prior PAD	327 (31.78%)	811 (34.67%)	0.11
Smoker	49 (4.75%)	193 (8.24%)	<0.001
NYHA functional class			<0.001
I	16 (1.56%)	45 (1.94%)	
II	239 (23.27%)	435 (18.72%)	
III	699 (68.06%)	1,586 (68.24%)	
IV	73 (7.11%)	258 (11.1%)	
Ejection fraction	57.37 ± 12.19	56.74 ± 12.05	0.17
Hypertension	922 (89.43%)	2,134 (91.16%)	0.128
Diabetes	381 (36.95%)	903 (38.61%)	0.384
Atrial fibrillation/flutter	313 (30.36%)	915 (39.17%)	<0.001
Severe chronic lung disease	78 (7.61%)	224 (9.62%)	0.07
Prior PCI	276 (26.77%)	726 (31.04%)	0.014
Prior CABG	218 (21.14%)	517 (22.08%)	0.573
Prior Nonaortic valve procedure	19 (1.85%)	61 (2.61%)	0.223
Status elective	978 (94.86%)	2,189 (93.51%)	0.151
Cardiac arrest	10 (0.97%)	26 (1.11%)	0.854
Preinotropes	14 (1.36%)	21 (0.9%)	0.303
KCCQ-12 overall	52.38 ± 24.13	49.47 ± 24.25	0.002
5-m walk (s)	7.17 ± 2.81	7.81 ± 3.59	<0.001
Postprocedure stroke	4 (0.39%)	16 (0.68%)	0.432
Any vascular complication (major or minor)	30 (2.91%)	76 (3.25%)	0.682
Pacemaker	78 (7.57%)	193 (8.24%)	0.549

Values are n (%), mean ± SD, or median (IQR).

CABG = coronary artery bypass graft; KCCQ-12 = 12-item Kansas City Cardiomyopathy Questionnaire; PAD = peripheral artery disease; PCI = percutaneous coronary intervention; STS = Society of Thoracic Surgeons; TAVR = transcatheter aortic valve replacement; TIA = transient ischemic attack.

FIGURE 2 Unadjusted Rates of CR Participation Across STS Risk Score, Baseline KCCQ Overall Score, and Baseline 5-m Walk Time



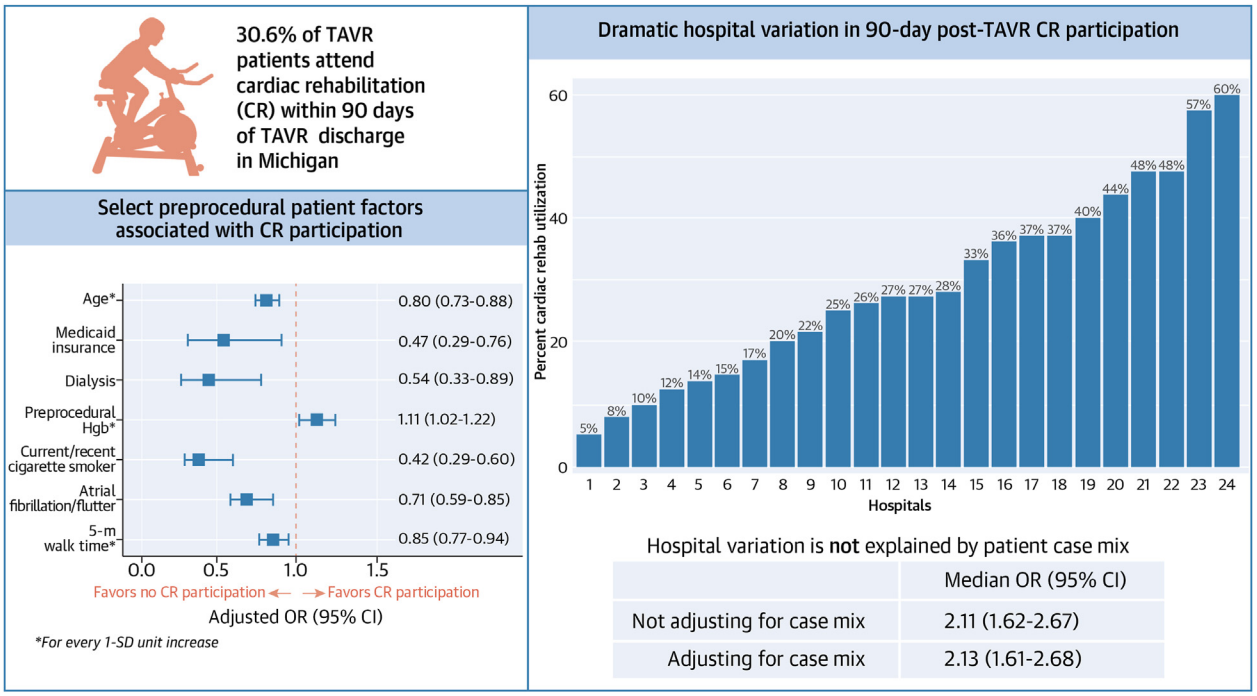
The Society of Thoracic Surgeons predicted risk of mortality is stratified into low risk (<4%), intermediate risk (≥4%-<8%), and high risk (≥8%). Baseline Kansas City Cardiomyopathy Questionnaire overall scores and 5-m walk times were stratified into quartiles. CR = cardiac rehabilitation; KCCQ = Kansas City Cardiomyopathy Questionnaire; STS = Society of Thoracic Surgeons.

participation after TAVR are more similar to 90-day CR participation rates after PCI[15,23,24] than they are for open heart surgeries like coronary artery bypass graft surgery, which has 90-day and 1-year CR participation rates of ~50%.[24,25] Using claims from MVC, our team recently demonstrated that rates of CR participation within 90 days after SAVR or TAVR discharge were 50.9% and 28.9%, respectively.[26] Moreover, within-hospital CR participation rates were significantly correlated across treatment strategies for aortic valve replacement. In the current study, we have further expanded upon our prior work by linking MVC administrative claims with rich clinical registry data. By including granular patient-level demographic and clinical data we were able to: 1) assess whether specific clinical comorbidities and postprocedural outcomes were related to downstream CR participation; and 2) more completely capture and adjust for patient case mix when evaluating hospital-level variation in CR participation.

The reason for these differences in participation rates across cardiovascular diagnoses and procedures is unclear. One possibility is that TAVR patients may be more frail and medically complex than patients who undergo SAVR, thus these TAVR patients (or their physicians and caregivers) may believe that they would not derive benefit from CR. However, CR is a multifaceted intervention that not only includes monitored exercise training but also education on heart-healthy living, counseling on stress management, and psychological support. Moreover, through evaluations by exercise physiologists and other CR providers, personalized exercise plans are tailored according to the vast differences in medical complexity, baseline functioning, and physical limitations across patients.

Although there is a paucity of evidence demonstrating the effectiveness of CR among patients undergoing TAVR,[27,28] Goel et al[18] elegantly demonstrated the potential benefits of improving physical functioning after TAVR. Using data from the REPRISE III (Repositionable Percutaneous Replacement of Stenotic Aortic Valve Through Implantation of Lotus Valve System-Randomized Clinical Evaluation) trial, the authors found that an individual's gait speed at 1 year, not at baseline, was significantly associated with death or hospitalization between years 1 and 2 after TAVR. In the same study, the authors reported remarkable variation in trajectories of physical functioning after TAVR, with a quarter of patients experiencing a clinically meaningful decline in their gait speed at 1 year. This finding is particularly important

CENTRAL ILLUSTRATION **Select Patient Predictors of CR Participation After TAVR and Hospital Variation in 90-Day CR Participation**



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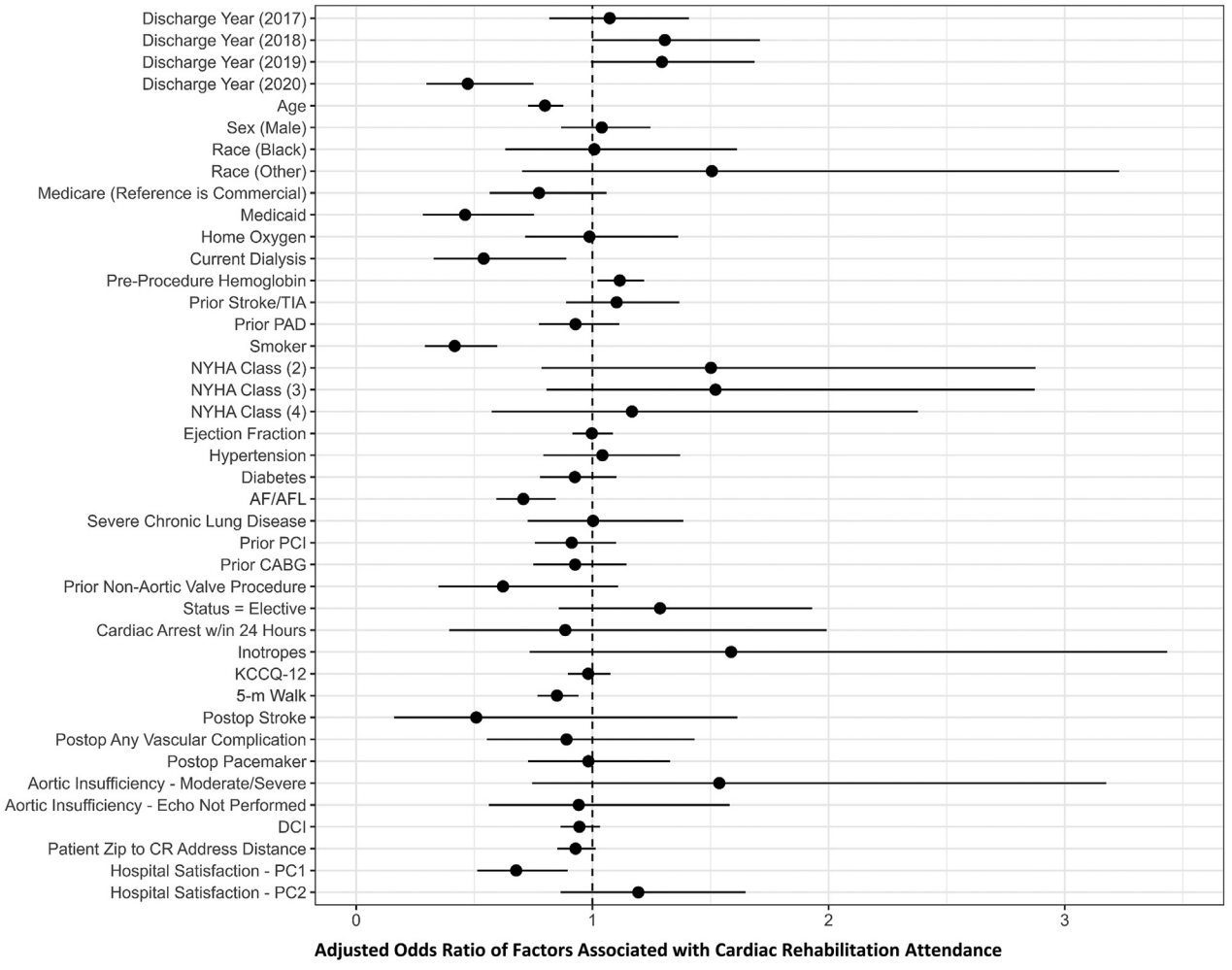
CR = cardiac rehabilitation; Hgb = hemoglobin (g/dL); TAVR = transcatheter aortic valve replacement.

in light of our study finding that patients who had longer pre-TAVR 5-m walk times (eg, walked slower) were less likely to participate in CR after discharge. Given that an individual's gait speed after TAVR at 1 year is prognostically important, using CR to improve physical functioning may be of particular interest in this group of patients.

Similar to prior studies evaluating predictors of CR participation after qualifying cardiovascular events, we found age, and insurance type to be significant predictors of CR participation after TAVR.[23,29-31] We did not find evidence that post-TAVR in-hospital complications were significantly associated with CR participation. However, it is important to note the relatively infrequent occurrence of many of these complications as well as the overall small sample size of our study to potentially limit our ability to detect statistically significant associations between complications after the procedure and CR participation. Moreover, patients with severe TAVR complications such as debilitating stroke may have been discharged to a skilled nursing facility instead of their home and thus were excluded from the primary analysis. In a sensitivity analysis including all patients discharged alive, postprocedural in-hospital stroke was associated with a significantly lower odds of participating in CR compared with patients who did not suffer a postprocedural stroke. Future research should be directed at understanding the mechanisms by which complications after TAVR are associated with poorer short- and long-term outcomes,[32,33] and whether CR may be effective in improving patient outcomes among those who have experienced a complication.

Lastly, we report marked variation in rates of CR participation after TAVR across 24 hospitals, with rates ranging from 5% to 60%. We report a MOR of approximately 2.13 after accounting for differences in patient case mix. Put another way, if 2 hospitals were randomly selected and treated the same hypothetical patient, and then this was repeated over all possible pairs of hospitals, in half of the pairs, the odds of participating in CR within 90 days after

FIGURE 3 Patient Demographic, Socioeconomic, Clinical, and Hospital Factors Associated With CR Participation



The central black circles represent the point estimates for the adjusted odds ratios with corresponding 95% confidence intervals (horizontal black lines). AF = atrial fibrillation; AFL = atrial flutter; CABG = coronary artery bypass graft; CR = cardiac rehabilitation; DCI = Distresses Communities Index; KCCQ-12 = 12-item Kansas City Cardiomyopathy Questionnaire; PAD = peripheral artery disease; PC = principal component; PCI = percutaneous coronary intervention; TIA = transient ischemic attack.

TAVR at one hospital would be at least twice that of the other hospitals. Inclusion of detailed demographic, socioeconomic, and clinical factors derived from a clinical registry did not substantially explain hospital-level variation in post-TAVR CR enrollment.

We also found that patient-reported hospital quality, derived from HCAHPS responses, was

TABLE 2 Change in Variance Component Statistics Across 3 Models

Model	Variance Components	Median OR (95% CI)	ICC (95% CI)	PCV Compared With Model 1	PCV Compared With Prior Model
Model 1	0.61	2.11 (1.62-2.67)	0.16 (0.07-0.24)		
Model 2	0.63	2.13 (1.61-2.68)	0.16 (0.07-0.25)	−2.74	−2.74
Model 3	0.45	1.9 (1.46-2.28)	0.12 (0.05-0.19)	25.9	27.9

ICC = intraclass correlation coefficient; PCV = proportional change in variance.

significantly associated with post-TAVR CR participation. We previously found HCAHPS responses to be associated with CR enrollment after PCI.[15] Moreover, the hospital where one undergoes TAVR is a strong predictor of CR participation, independent of patient demographic, socioeconomic, and clinical factors. These findings highlight the importance of identifying hospital-level barriers and facilitators to CR enrollment and adherence after qualifying cardiovascular events. This is work that our statewide structural heart and CR consortium plans to address through engagement with diverse collaborative quality improvement organizations and stakeholders across the state of Michigan.

STUDY LIMITATIONS. Our findings should be considered in the context of important limitations. First, our findings were limited to a single state with a strong investment in collaborative quality improvement programs that bring together hospitals and health care professionals across Michigan to improve care quality through sharing of best practices and quality improvement initiatives.[34] Thus, our findings may not be generalizable to other states. Second, we did not capture CR referrals as the transcatheter valve therapy registry did not collect information regarding in-hospital referral before TAVR discharge until recently. Therefore, we do not know if the variation in CR participation after TAVR was due to variation in CR referral patterns. Third, based on how claims-based episodes of care are created, patients who underwent TAVR after a hospitalization or procedure that triggered the initiation of a different 90-day episode of care, based on MVC's episode creation algorithm, would not have a TAVR 90-day episode created. As such, our study cohort may not be representative of a real-world TAVR population but rather a cohort of patients who underwent isolated TAVR without recent coexistent indications for CR such as PCI or admissions for acute myocardial infarction or heart failure. Finally, there may be unmeasured patient factors that may account for differences in CR participation such as general unwillingness or inability to participate due to lack of family support or financial constraints, for example.

CONCLUSIONS

With the continued growth of TAVR for the treatment of severe AS and concomitant improvements in postprocedural outcomes due to periprocedural care innovations, including the use of moderate sedation and same-day discharge, we highlight an important gap in the postdischarge care of this ever-growing population of patients. However, this gap is not unique to TAVR but persists across the spectrum of qualifying cardiovascular conditions and diagnoses.[21,24] Despite heterogeneity in patient complexity across TAVR sites, after accounting for patient complexity using rich clinical registry data, substantial hospital-level variation in post-TAVR CR participation remained. Thus, identifying hospital and health system-level factors and processes of care that promote CR participation after TAVR and subsequently implementing those strategies across health systems are a critical next step to improving CR participation after TAVR.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: CR carries a Class I recommendation after many cardiovascular procedures including valve replacement. We demonstrated significant underutilization of CR among patients who underwent TAVR in the state of Michigan with rates similar to that of CR use after PCI. There is substantial hospital variation in the rates CR use after TAVR that is not explained by differences in patient case mix. Patients who are more frail are less likely to use CR and may be the population of patients most likely to benefit from CR.

TRANSLATIONAL OUTLOOK: As the U.S. health care system continues to incentivize high-quality and high-value care, health systems may want to design initiatives at the hospital and health system level to improve CR use after TAVR.

REFERENCES

1. Levine GN, Bates ER, Blankenship JC, et al. 2011 ACCF/AHA/SCAI guideline for percutaneous coronary intervention. A report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. *J Am Coll Cardiol*. 2011;58:e44–122.

2. Piepoli MF, Hoes AW, Agewall S, et al. 2016 European guidelines on cardiovascular disease prevention in clinical practice: the Sixth Joint Task Force of the European Society of Cardiology and other Societies on Cardiovascular Disease Prevention in Clinical Practice (constituted by representatives of 10 societies and by invited experts) developed with the special contribution of the European Association for Cardiovascular Prevention & Rehabilitation (EACPR). *Eur Heart J*. 2016;37:2315–2381.

3. David HL, Smith Peter K, Anderson Jeffrey L, et al. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery. *J Am Coll Cardiol*. 2011;58(24):e123–e210.

4. Ades PA. Cardiac rehabilitation and secondary prevention of coronary heart disease. *N Engl J Med*. 2001;345:892–902.

5. Anderson L, Oldridge N, Thompson DR, et al. Exercise-based cardiac rehabilitation for coronary heart disease: cochrane systematic review and meta-analysis. *J Am Coll Cardiol*. 2016;67:1–12.

6. Suaya JA, Stason WB, Ades PA, Normand S-LT, Shepard DS. Cardiac rehabilitation and survival in older coronary patients. *J Am Coll Cardiol*. 2009;54:25–33.

7. Decision memo for cardiac rehabilitation programs (CAG-00089R) [Internet]. Accessed January 26, 2021. https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx?NCAId=164&NcaName=Cardiac+Rehabilitation+Programs&DocID=CAG-00089R

8. Otto CM, Kumbhani DJ, Alexander KP, et al. 2017 ACC expert consensus decision pathway for transcatheter aortic valve replacement in the management of adults with aortic stenosis: a report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. *J Am Coll Cardiol*. 2017;69:1313–1346.

9. Afilalo J, Lauck S, Kim DH, et al. Frailty in older adults undergoing aortic valve replacement: the FRAILTY-AVR study. *J Am Coll Cardiol*. 2017;70:689–700.

10. Kim DH, Afilalo J, Shi SM, et al. Evaluation of changes in functional status in the year after aortic valve replacement. *JAMA Intern Med*. 2019;179:383–391.

11. STS/TVT data collection forms [Internet]. Accessed April 4, 2022. https://www.ncdr.com/WebNCDR/tvt/publicpage/data-collection

12. Ellimoottil C, Syrjamaki JD, Voit B, Guduguntla V, Miller DC, Dupree JM. Validation of a claims-based algorithm to characterize episodes of care. *Am J Manag Care*. 2017;23:e382–e386.

13. Robinson D. Fuzzyjoin: join tables together on Inexact matching [Internet]. Accessed April 4, 2022. https://CRAN.R-project.org/package=fuzzyjoin

14. Patient survey (HCAHPS) - hospital [Internet]. Patient survey (HCAHPS) - hospital. 2022. https://data.cms.gov/provider-data/dataset/dgck-syfz

15. Sukul D, Seth M, Thompson MP, et al. Hospital and operator variation in cardiac rehabilitation referral and participation after percutaneous coronary intervention: Insights from Blue Cross Blue Shield of Michigan cardiovascular consortium. *Circ Cardiovasc Qual Outcomes*. 2021;14:e008242.

16. Green CP, Porter CB, Bresnahan DR, Spertus JA. Development and evaluation of the Kansas city cardiomyopathy questionnaire: a new health status measure for heart failure. *J Am Coll Cardiol*. 2000;35:1245–1255.

17. Arnold SV, Spertus JA, Lei Y, et al. Use of the Kansas city cardiomyopathy questionnaire for monitoring health status in patients with aortic stenosis. *Circ Heart Fail*. 2013;6:61–67.

18. Goel K, O'Leary JM, Barker CM, et al. Clinical implications of physical function and resilience in patients undergoing transcatheter aortic valve replacement. *J Am Heart Assoc*. 2020;9:e017075.

19. R Core Team. R: a language and environment for statistical computing [Internet]. Accessed February 20, 2022. https://www.R-project.org/

20. Ades PA, Keteyian SJ, Wright JS, et al. Increasing cardiac rehabilitation participation from 20% to 70%: a road map from the million hearts cardiac rehabilitation collaborative. *Mayo Clin Proc*. 2017;92:234–242.

21. Keteyian SJ, Jackson SL, Chang A, et al. Tracking cardiac rehabilitation utilization in medicare beneficiaries: 2017 update. *J Cardiopulm Rehabil Prev*. 2022;42(4):235–245.

22. Patel DK, Duncan MS, Shah AS, et al. Association of cardiac rehabilitation with decreased hospitalization and mortality risk after cardiac valve surgery. *JAMA Cardiology*. 2019;4:1250.

23. Sukul D, Seth M, Barnes GD, et al. Cardiac rehabilitation use after percutaneous coronary intervention. *J Am Coll Cardiol*. 2019;73:3148–3152.

24. Ritchey Matthew D, Sha M, Jessica M, et al. Tracking cardiac rehabilitation participation and completion among medicare beneficiaries to inform the efforts of a National initiative. *Circ Cardiovasc Qual Outcomes*. 2020;13:e005902.

25. Thompson MP, Yaser JM, Hou H, et al. Determinants of hospital variation in cardiac rehabilitation enrollment during coronary artery disease episodes of care. *Circ Cardiovasc Qual Outcomes*. 2021;14:14e007144.

26. Guduguntla V, Yaser JM, Keteyian SJ, et al. Variation in cardiac rehabilitation participation during aortic valve replacement episodes of care. *Circ Cardiovasc Qual Outcomes*. 2022;15(7):e009175.

27. Anayo L, Rogers P, Long L, Dalby M, Taylor R. Exercise-based cardiac rehabilitation for patients following open surgical aortic valve replacement and transcatheter aortic valve implant: a systematic review and meta-analysis. *Open Heart*. 2019;6:e000922.

28. Ribeiro GS, Melo RD, Deresz LF, Dal Lago P, Pontes MR, Karsten M. Cardiac rehabilitation programme after transcatheter aortic valve implantation versus surgical aortic valve replacement: systematic review and meta-analysis. *Eur J Prev Cardiol*. 2017;24:688–697.

29. Beatty AL, Bradley SM, Maynard C, McCabe JM. Referral to cardiac rehabilitation after percutaneous coronary intervention, coronary artery bypass surgery, and valve surgery: data from the clinical outcomes assessment program. *Circ Cardiovasc Qual Outcomes*. 2017;10:e003364.

30. Bachmann JM, Huang S, Gupta DK, et al. Association of neighborhood socioeconomic context with participation in cardiac rehabilitation. *J Am Heart Assoc*. 2017;6:e006260.

31. Peters AE, Keeley EC. Trends and predictors of participation in cardiac rehabilitation following acute myocardial infarction: data from the behavioral risk factor surveillance system. *J Am Heart Assoc*. 2017;7:e007664.

32. Arnold SV, Zhang Y, Baron SJ, et al. Impact of short-term complications on mortality and quality of life after transcatheter aortic valve replacement. *J Am Coll Cardiol Intv*. 2019;12:362–369.

33. Arnold SV, Manandhar P, Vemulapalli S, et al. Impact of short-term complications of TAVR on longer-term outcomes: results from the STS/ACC transcatheter valve therapy registry. *Eur Heart J Qual Care Clin Outcomes*. 2020;7(2):208–213.

34. Share DA, Campbell DA, Birkmeyer N, et al. How a regional collaborative of hospitals and physicians in Michigan cut costs and improved the quality of care. *Health Aff (Millwood)*. 2011;30:636–645.

KEY WORDS cardiac rehabilitation, health services research, hospital variation, TAVR

APPENDIX For supplemental methods, tables and a figure, please see the online version of this paper.