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ORIGINAL RESEARCH

Hospital Variation in 30-Day Readmissions Following Transcatheter Aortic Valve Replacement

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BACKGROUND: Data on hospital variation in 30-day readmission rates after transcatheter aortic valve replacement (TAVR) are limited. Further, whether such variation is explained by differences in hospital characteristics and hospital practice patterns remains unknown.

METHODS AND RESULTS: We used the 2017 Nationwide Readmissions Database to identify hospitals that performed at least 5 TAVRs. Hierarchical logistic regression models were used to examine between-hospital variation in 30-day all-cause risk-standardized readmission rate (RSRR) after TAVR and to explore reasons underlying hospital variation in 30-day RSRR. The study included 27 091 index TAVRs performed across 325 hospitals. The median (interquartile range) hospital-level 30-day RSRR was 11.9% (11.1%–12.8%) ranging from 8.8% to 16.5%. After adjusting for differences in patient characteristics, there was significant between-hospital variation in 30-day RSRR (hospital odds ratio, 1.59; 95% CI, 1.39–1.77). Differences in length of stay and discharge disposition accounted for 15% of the between-hospital variance in RSRRs. There was no significant association between hospital characteristics and 30-day readmission rates after TAVR. There was statistically significant but weak correlation between 30-day RSRR after TAVR and that after surgical aortic valve replacement, percutaneous coronary intervention, acute myocardial infarction, heart failure, and pneumonia (r=0.132–0.298; P<0.001 for all). Causes of 30-day readmission varied across hospitals, with noncardiac readmissions being more common at the bottom 5% hospitals (ie, those with the highest RSRRs).

CONCLUSIONS: There is significant variation in 30-day RSRR after TAVR across hospitals that is not entirely explained by differences in patient or hospital characteristics as well as hospital-wide practice patterns. Noncardiac readmissions are more common in hospitals with the highest RSRRs.

Key Words: aortic stenosis ■ hospital variation ■ readmission ■ transcatheter aortic valve replacement

Thirty-day readmissions are used as a hospital performance metric by the Centers for Medicare and Medicaid Services (CMS) for certain cardiac and noncardiac conditions.[1] Unplanned readmissions are also associated with poor patient outcomes and increased healthcare costs.[2,3] Transcatheter aortic valve replacement (TAVR) has emerged as an effective and safe treatment option for patients with symptomatic severe aortic stenosis across the entire spectrum of surgical risk. Thirty-day all-cause readmission rates after TAVR have ranged from 16.0% to 20.9% in previous studies.[3–5] Technological advancement, increased operator experience, and decrease in patient risk profile have resulted in substantial improvements in TAVR outcomes over the past several years, including a decline in 30-day readmission rates.[6,7] Yet, despite stringent patient selection criteria and standardized procedural techniques, there remains significant hospital variation

CLINICAL PERSPECTIVE

What Is New?

- There is significant between-hospital variation in 30-day risk-standardized readmission rates after transcatheter aortic valve replacement that is not entirely explained by differences in patient or hospital characteristics as well as hospital-wide practice patterns.
- Causes of 30-day readmission after transcatheter aortic valve replacement vary across hospitals with noncardiac readmissions being more common at the bottom 5% hospitals (ie, those with highest risk-standardized readmission rates).

What Are the Clinical Implications?

- Future qualitative/mixed methods studies are needed to determine the unique organizational practices that differentiate transcatheter aortic valve replacement hospitals with readmission rates below and above the national average and to identify modifiable practices associated with decreased readmission rates.

Nonstandard Abbreviations and Acronyms

CMS Centers for Medicare and Medicaid Services
HRRP Hospital Readmissions Reduction Program
NRD Nationwide Readmissions Database
RSRR risk-standardized readmission rate
SAVR surgical aortic valve replacement
SRR standardized rate ratio
TAVR transcatheter aortic valve replacement

in TAVR outcomes, including mortality, stroke, and major vascular/bleeding complications.[8–10] Data on hospital variation in 30-day readmission rates after TAVR are limited.[4] Further, whether such variation in 30-day readmission rates can be explained by differences in hospital characteristics and hospital practice patterns remains unknown. Identifying TAVR hospitals with 30-day readmission rates below and above the national average could enable the conduct of future qualitative or mixed-methods studies to identify modifiable practices associated with decreased readmission rates.[11,12]

The primary objective of this study was to determine hospital-level variation in 30-day readmission rates after TAVR, and to identify hospital characteristics associated with 30-day readmissions. Further,

to understand if hospital-wide practice patterns and processes of care may influence readmission rates, we examined the correlation between hospital-level 30-day readmission rates after TAVR and those after other cardiovascular procedures (surgical aortic valve replacement [SAVR] and percutaneous coronary intervention [PCI]) and Hospital Readmissions Reduction Program (HRRP) target conditions (acute myocardial infarction [AMI], heart failure [HF], and pneumonia).

METHODS

Data Source

We used the 2017 Nationwide Readmissions Database (NRD) for this study. The NRD is part of a family of publicly available, all-payer databases developed by the Agency for Healthcare Research and Quality for the Healthcare Cost and Utilization Project (HCUP). The 2017 NRD contains discharge data from 28 geographically dispersed states, accounting for 60.0% of the total US resident population and 58.2% of all US hospitalizations.[13] The NRD includes all discharge records of patients treated in US community hospitals, excluding rehabilitation and long-term acute care facilities. The NRD contains verified patient linkage numbers that can be used to track a patient across hospitals within a state while protecting the privacy of individual patients, physicians, and hospitals. The patient linkage numbers do not track the same individual across years. This study was deemed exempt by the Mass General Brigham Institutional Review Board since the NRD is a publicly available database that contains deidentified patient information. The authors declare that all supporting data are available within the article.

Study Population

Hospitals performing ≥5 TAVRs were included in the study. *International Classification of Diseases, Tenth Revision, Clinical Modification* (*ICD-10-CM*) or Procedure Coding System, or HCUP Clinical Classification Software codes were used to identify index hospitalizations for TAVR, SAVR, PCI, AMI, HF, or pneumonia (Table 1). Index hospitalization was defined as the first hospitalization in the calendar year for the procedure/diagnosis of interest. Since an individual patient may have undergone multiple procedures during the study period, we used the following hierarchy of procedures to define the index hospitalization: SAVR > TAVR > PCI. Thus, patients who underwent PCI before TAVR were included in the TAVR cohort for the primary analyses. Additionally, we performed sensitivity analysis after excluding patients

Table 1. *International Classification of Diseases, Tenth Revision, Clinical Modification* or Procedure Coding System, Healthcare Cost and Utilization Project Clinical Classification Software, and Centers for Medicare and Medicaid Services Condition Category Codes Used to Define Index Hospitalizations and Comorbidities

	ICD-10-CM/PCS	HCUP CCS	CMS CC
TAVR	02RF37Z, 02RF38Z, 02RF3JZ, 02RF3KZ, 02RF37H, 02RF38H, 02RF3JH, 02RF3KH	…	…
SAVR	02RF07Z, 02RF08Z, 02RF0JZ, 02RF0KZ	…	…
PCI	…	45	…
AMI	I21.01, I21.02, I21.09, I21.11, I21.19, I21.21, I21.29, I21.3, I21.4, I21.9	…	…
HF	I50.1, I50.2x, I50.3x, I50.4x, I50.81x, I50.82, I50.83, I50.84, I50.89, I50.9, I11.0, I13.0, I13.2	…	…
Pneumonia	…	122	…
Comorbidities			
Smoking	Z72.0, Z87.891, F17.200, O99.33x		
Dyslipidemia	E78.00, E78.01, E78.1, E78.2, E78.3, E78.41, E78.49, E78.5	…	…
Diabetes mellitus	…	…	17–19, 122–123
Atrial fibrillation	I48.0, I48.1, I48.2, I48.91	…	…
Known CAD	…	…	CC 88–89
Prior MI	I25.2, I22.0, I22.1, I22.2, I22.8, I22.9	…	…
Prior PCI	Z95.5, Z98.61	…	…
Prior CABG	Z95.1	…	…
Prior TIA/stroke	Z86.73	…	…
Prior PPM/implantable cardioverter-defibrillator	Z95.0, Z95.810	…	…
Peripheral vascular disease		…	106–109
Carotid artery disease	I65.21, I65.22, I65.23, I65.29	…	…
Chronic kidney disease	…	…	136–139
ESRD	…	…	134
Chronic pulmonary disease	…	…	111–113
Chronic liver disease	…	…	27–32
Anemia	…	…	49
Depression	…	…	61
Drug/alcohol abuse	…	…	54–56
Fluid and electrolyte disorders	…	…	24
Protein-calorie malnutrition	…	…	21
Cancer	…	…	9–14

Hypertension, obesity, coagulopathy, and hypothyroidism were defined using the Elixhauser comorbidity variables in the Nationwide Readmissions Database. AMI indicates acute myocardial infarction; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CC, condition category; CCS, clinical classification software; CMS, Centers for Medicare and Medicaid Services; ESRD, end-stage renal disease on dialysis; HCUP, Healthcare Cost and Utilization Project; HF, heart failure; *ICD-10-CM, International Classification of Diseases, Tenth Revision, Clinical Modification;* PCI, percutaneous coronary intervention; PCS, procedure coding system; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement; and TIA, transient ischemic attack.

who underwent PCI during or within 30 days before TAVR. For AMI, HF, and pneumonia, only the primary diagnosis was used to identify index hospitalizations. Further, patients who underwent TAVR during a hospitalization for AMI, HF, or pneumonia were included in the TAVR cohort. For all index hospitalizations, we excluded patients if they (1) died during the index hospitalization, (2) left against medical advice, (3) were transferred to rehab, or (4) were hospitalized in December 2017 (to ensure minimum 30-day follow-up).

Patient and Hospital Characteristics

Data on patient demographics (age, sex, primary expected payer, median household income), admission status (elective versus nonelective), comorbidities (smoking, dyslipidemia, hypertension, diabetes mellitus, obesity, atrial fibrillation, HF, known coronary artery disease, prior myocardial infarction, prior PCI, prior coronary artery bypass grafting, prior transient ischemic attack/stroke, prior permanent pacemaker/implantable cardioverter-defibrillator, peripheral vascular disease, carotid artery disease, chronic kidney disease,

Table 2. Baseline Characteristics of Patients With and Without 30-Day Readmission After TAVR

Characteristics	Overall (n=27 091)	30-Day Readmission		P Value
		No (n=23 853)	Yes (n=3238)	
Age, y	81 (75–86)	81 (75–86)	82 (75–87)	0.004
Women	12 353 (45.6)	10 857 (45.5)	1496 (46.2)	0.46
Primary expected payer				0.002
Medicare	24 615 (91.0)	21 623 (90.8)	2992 (92.4)	
Medicaid	306 (1.1)	263 (1.1)	43 (1.3)	
Private	1636 (6.0)	1483 (6.2)	153 (4.7)	
Self-pay	93 (0.3)	84 (0.4)	<10 (<0.1)	
No charge	<10 (<0.1)	<10 (<0.1)	<10 (<0.1)	
Other	407 (1.5)	368 (1.5)	39 (1.2)	
Median household income				0.83
0–25th percentile	5120 (19.2)	4519 (19.2)	601 (18.8)	
26th–50th percentile	6993 (26.2)	6157 (26.2)	836 (26.2)	
51st–75th percentile	7301 (27.3)	6408 (27.2)	893 (27.9)	
76th–100th percentile	7311 (27.4)	6446 (27.4)	865 (27.1)	
Elective admission	21 716 (80.2)	19 390 (81.4)	2326 (71.9)	<0.001
Comorbidities				
Smoking	8768 (32.4)	7825 (32.8)	943 (29.1)	<0.001
Dyslipidemia	18 280 (67.5)	16 245 (68.1)	2035 (62.8)	<0.001
Hypertension	7774 (28.7)	7022 (29.4)	752 (23.2)	<0.001
Diabetes mellitus	7875 (29.1)	6881 (28.8)	994 (30.7)	0.029
Obesity	5109 (18.9)	4523 (19.0)	586 (18.1)	0.24
Atrial fibrillation	10 192 (37.6)	8698 (36.5)	1494 (46.1)	<0.001
Heart failure	20 693 (76.4)	18 022 (75.6)	2671 (82.5)	<0.001
Known CAD	18 898 (69.8)	16 614 (69.7)	2284 (70.5)	0.30
Prior MI	2918 (10.8)	2585 (10.8)	333 (10.3)	0.34
Prior PCI	5290 (19.5)	4734 (19.8)	556 (17.2)	<0.001
Prior CABG	4029 (14.9)	3632 (15.2)	397 (12.3)	<0.001
Prior TIA/stroke	2893 (10.7)	2519 (10.6)	374 (11.6)	0.09
Prior PPM/implantable cardioverter-defibrillator	2972 (11.0)	2620 (11.0)	352 (10.9)	0.85
Peripheral vascular disease	9439 (34.8)	8132 (34.1)	1307 (40.4)	<0.001
Carotid artery disease	1573 (5.8)	1413 (5.9)	160 (4.9)	0.024
Chronic kidney disease	9619 (35.5)	8164 (34.2)	1455 (44.9)	<0.001
ESRD	772 (2.8)	605 (2.5)	167 (5.2)	<0.001
Chronic pulmonary disease	7968 (29.4)	6870 (28.8)	1098 (33.9)	<0.001
Chronic liver disease	971 (3.6)	812 (3.4)	159 (4.9)	<0.001
Anemia	9509 (35.1)	8037 (33.7)	1472 (45.5)	<0.001
Coagulopathy	3324 (12.3)	2852 (12.0)	472 (14.6)	<0.001
Depression	2050 (7.6)	1764 (7.4)	286 (8.8)	0.003
Drug/alcohol abuse	1503 (5.5)	1317 (5.5)	186 (5.7)	0.60
Hypothyroidism	5232 (19.3)	4591 (19.2)	641 (19.8)	0.46
Fluid and electrolyte disorders	4090 (15.1)	3380 (14.2)	710 (21.9)	<0.001
Protein-calorie malnutrition	750 (2.8)	585 (2.5)	165 (5.1)	<0.001
Cancer	1278 (4.7)	1082 (4.5)	196 (6.1)	<0.001
Discharge quarter				0.28
1	6817 (25.2)	5986 (25.1)	831 (25.7)	
2	7461 (27.5)	6542 (27.4)	919 (28.4)	

(Continued)

Table 2. Continued

Characteristics	Overall (n=27 091)	30-Day Readmission		P Value
		No (n=23 853)	Yes (n=3238)	
3	7550 (27.9)	6654 (27.9)	896 (27.7)	
4	5263 (19.4)	4671 (19.6)	592 (18.3)	
Length of stay, d	2 (2–5)	2 (2–4)	3 (2–8)	<0.001
Discharge disposition				<0.001
Home (self-care)	17 109 (63.2)	15 535 (65.1)	1574 (48.6)	
Short-term hospital	65 (0.2)	49 (0.2)	16 (0.5)	
Skilled nursing facility	3209 (11.8)	2546 (10.7)	663 (20.5)	
Home health care	6707 (24.8)	5722 (24.0)	985 (30.4)	

Numbers in parentheses represent interquartile range for continuous variables and percentage for categorical variables. CABG indicates coronary artery bypass grafting; CAD, coronary artery disease; ESRD, end-stage renal disease on dialysis; MI, myocardial infarction; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; TAVR, transcatheter aortic valve replacement; and TIA, transient ischemic attack.

end-stage renal disease on dialysis, chronic pulmonary disease, chronic liver disease, anemia, coagulopathy, depression, drug/alcohol abuse, hypothyroidism, fluid and electrolyte disorders, protein-calorie malnutrition, and cancer), hospital characteristics (control/ownership, teaching status, bed size, location, and TAVR volume), discharge quarter, length of stay (LOS), and discharge disposition (nonhome versus home) were extracted. We used *International Classification of Diseases, Tenth Revision, Clinical Modification* or CMS Condition Category codes to define comorbidities (Table 1).

Outcomes Measured

The primary outcome of interest for this study was 30-day risk-standardized readmission rate (RSRR), defined as all-cause, nonelective (unplanned) readmission within 30 days of discharge from the index hospitalization. For patients who had >1 readmission within 30 days, only the first readmission was considered for analysis.

Statistical Analysis

Unweighted data were used for all analyses since we were interested in hospital-level readmission rates and not national estimates. Hospital characteristics were compared across quartiles of 30-day RSRR after TAVR. Continuous variables are presented as median (interquartile range [IQR]) and compared across quartiles using the Kruskal-Wallis test. Categorical variables are presented as frequency (percentage) and compared across the quartiles using the Pearson chi-square test.

To examine between-hospital variation in 30-day readmissions after TAVR, we used hierarchical logistic regression model with random hospital-level intercept. The model included patient characteristics
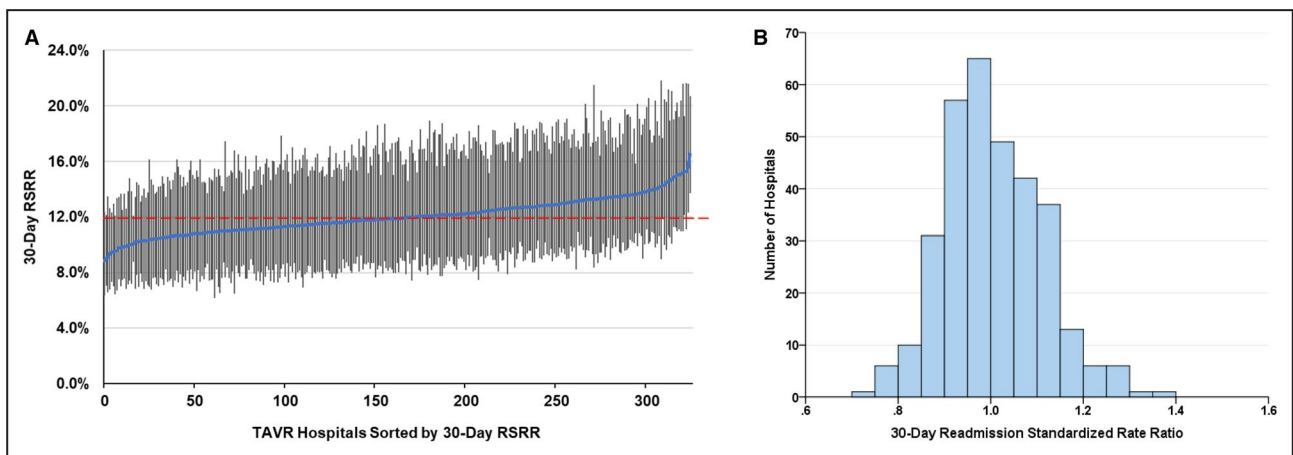
Figure 1. Hospital variation in 30-day RSRR after TAVR.
A, Hospital-level 30-day RSRR after TAVR. Thirty-day RSRR point estimates (blue dots) with corresponding 95% CIs (vertical lines) for each TAVR hospital are depicted. The red line represents the mean 30-day RSRR for all TAVR hospitals included in the study. The *x* axis represents unique TAVR hospitals sorted from lowest to highest 30-day RSRR. **B**, Histogram of 30-day readmission standardized rate ratio (SRR). The SRR provides a relative comparison of the predicted and expected readmission rates for each hospital. Thus, a SRR of >1.0 reflects higher-than-expected readmission rates for the patients who underwent TAVR at that hospital, after adjusting for patient-level covariates. RSRR indicates risk-standardized readmission rate; and TAVR, transcatheter aortic valve replacement.

Table 3. Hospital Characteristics Across Quartiles of 30-Day RSRR Following TAVR

| Characteristic | Overall (n=325) | 30-Day RSRR After TAVR | | | | P Value |
		Quartile 1 8.8%–11.0% (n=81)	Quartile 2 11.1%–11.8% (n=81)	Quartile 3 11.9%–12.7% (n=81)	Quartile 4 12.8%–16.5% (n=82)	
Bed size, n (%)						0.47
Small	21 (6.5)	<10 (4.9)	<10 (8.6)	<10 (7.4)	<10 (4.9)	
Medium	79 (24.3)	26 (32.1)	15 (18.5)	17 (21.0)	21 (25.6)	
Large	225 (69.2)	51 (63.0)	59 (72.8)	58 (71.6)	57 (69.5)	
Control/ownership, n (%)						0.19
Government	31 (9.5)	<10 (6.2)	<10 (9.9)	<10 (9.9)	10 (12.2)	
Private, not-for-profit	256 (78.8)	71 (87.7)	63 (77.8)	65 (80.2)	57 (69.5)	
Private, investor-owned	38 (11.7)	<10 (6.2)	<10 (12.3)	<10 (9.9)	15 (18.3)	
Teaching status, n (%)						0.22
Teaching	272 (83.7)	71 (87.7)	62 (76.5)	70 (86.4)	69 (84.1)	
Nonteaching	53 (16.3)	10 (12.3)	19 (23.5)	11 (13.6)	13 (15.9)	
Location,* n (%)						0.53
Large metropolitan	174 (53.5)	45 (55.6)	40 (49.4)	40 (49.4)	49 (59.8)	
Small metropolitan	147 (45.2)	34 (42.0)	41 (50.6)	40 (49.4)	32 (39.0)	
Micropolitan	<10 (1.2)	<10 (2.5)	0 (0.0)	<10 (1.2)	<10 (1.2)	
Non-urban residual	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
TAVR volume, median (IQR)	68 (41–117)	84 (46–149)	62 (35–93)	61 (35–91)	77 (52–127)	0.007

IQR indicates interquartile range; RSRR, risk-standardized readmission rate; and TAVR, transcatheter aortic valve replacement.

*Based on the county of the hospital, as identified by the American Hospital Association. The 12 categories of the Urban Influence Codes are combined into 4 broader categories that differentiate between large and small metropolitan, micropolitan, and a nonurban residual.

(demographics, admission status, comorbidities, and discharge quarter) as fixed effects. The C-statistic of this model was 0.64, indicating a modest discrimination, which is similar to that of the CMS readmission models for conditions included in the HRRP.[14] This model was used to calculate hospital-level 30-day RSRR as the ratio of the number of predicted to expected readmissions (ie, standardized rate ratio [SRR]) multiplied by the overall unadjusted readmission rate, as previously described.[15] Hierarchical logistic regression models were also used to calculate 30-day RSRR after SAVR, PCI, AMI, HF, and pneumonia. Models for SAVR and PCI adjusted for patient demographics, admission status, comorbidities, discharge quarter, LOS, and discharge disposition. Models for AMI, HF, and pneumonia included covariates used in the CMS models with minor modifications.

We used SRR and hospital odds ratio (OR) to formally assess between-hospital variation in 30-day readmissions following TAVR. The SRR provides a relative comparison of the predicted and expected readmission rates for each hospital with respect to the patients who underwent TAVR at that hospital. Thus, an SRR of >1.0 reflects higher-than-expected readmission rates for the patients who underwent TAVR at that hospital, after adjusting for patient-level covariates. To quantify between-hospital variation in readmission rates, we used the estimated random-effects SD to compute hospital OR,

which represents the odds of 30-day readmission for a patient undergoing TAVR at a hospital that is 1 SD above the average 30-day readmission rate relative to undergoing TAVR at a hospital that is 1 SD below the average, adjusting for patient characteristics.[4]

To explore potential reasons underlying hospital variation in 30-day RSRR, we performed the following analyses. First, we introduced LOS (as a proxy for in-hospital complications) and discharge disposition at the patient level as "explanatory" variables in the original model used to calculate 30-day RSRR. We then calculated the relative change in variance in hospital-level RSRRs between the 2 models by subtracting the variance of the estimates derived from the explanatory model from the variance of the estimates derived from the original model, and then dividing the difference by the variance of the estimates derived from the original model. This value can be interpreted as the percentage of between-hospital variation in 30-day RSRR attributable to factors introduced in the explanatory model. This approach has been used in prior studies.[16] Second, to examine the association between hospital characteristics and 30-day RSRR, we fit another hierarchical logistic regression model that included hospital-specific characteristics (bed size, control/ownership [government, private not-for-profit, and private investor-owned], teaching status, location [large metropolitan, small metropolitan, micropolitan, and a nonurban residual], and TAVR volume). This model was

Table 4. Association Between Hospital-Level Characteristics and 30-Day Readmission Following TAVR

Characteristics	Adjusted OR (95% CI)	P Value
Bed size		
Small	1.0 [Reference]	…
Medium	0.98 (0.78–1.25)	0.89
Large	0.99 (0.84–1.15)	0.85
Control/ownership		
Government	1.0 [Reference]	…
Private, not-for-profit	0.89 (0.77–1.02)	0.10
Private, investor-owned	0.97 (0.88–1.08)	0.59
Teaching status		
Nonteaching	1.0 [Reference]	…
Teaching	0.96 (0.84–1.10)	0.57
Location		
Large metropolitan	1.0 [Reference]	…
Small metropolitan or micropolitan	0.95 (0.88–1.04)	0.29
TAVR volume		
Quartile 1	1.0 [Reference]	…
Quartile 2	0.99 (0.82–1.19)	0.92
Quartile 3	1.08 (0.90–1.29)	0.40
Quartile 4	1.02 (0.90–1.16)	0.73

OR indicates odds ratio; and TAVR, transcatheter aortic valve replacement.

used to estimate adjusted ORs and 95% CIs for hospital-specific characteristics. Finally, we used Pearson correlation coefficients (r) to test correlation between 30-day RSRR after TAVR and that after SAVR, PCI, AMI, HF, and pneumonia. Based on the value of r, the magnitude of correlation was interpreted as negligible (0.00–0.10), weak (0.11–0.39), moderate (0.40–0.69), strong (0.70–0.89), or very strong (0.90–1.00).[17]

To determine the causes of 30-day readmissions, we reviewed the primary diagnosis of each readmission record and grouped them into clinically meaningful categories using the Healthcare Cost and Utilization Project Clinical Classification Software codes. Causes of 30-day readmission were compared across the top 5%, middle 90%, and bottom 5% hospitals ranked according to their SRRs.

Missing data for covariates were rare (1.4%–1.6% for median household income, 0.1%–0.4% for admission status, and 0.1%–0.2% for primary expected payer in TAVR, SAVR, and PCI cohorts). Missing data were imputed using the Imputation and Variance Estimation Software (IVEware, Ann Arbor, MI), which uses a sequential regression multivariate imputation approach for multiply imputing missing values in a data set.

Statistical analyses were performed using SAS, version 9.3 (SAS Institute, Inc., Cary, NC). All P values were 2-sided, with a significance threshold of <0.05.

RESULTS

The final study population included 27 091 index TAVR procedures performed across 325 hospitals in the United States. Baseline characteristics of patients with and without 30-day readmission after TAVR are summarized in Table 2.

Hospital Variation in 30-Day RSRR Following TAVR

Hospital-level observed 30-day readmission rates ranged from 0% to 40.0% (IQR, 8.3%–15.4%). After adjusting for differences in patient characteristics, the median (IQR) hospital-level 30-day RSRR was 11.9% (11.1%–12.8%) ranging from 8.8% to 16.5% (Figure 1A). There was significant between-hospital variation in 30-day RSRR such that a patient's predicted odds of 30-day readmission were ≈60% higher if treated at a hospital 1 SD above the average compared with a hospital 1 SD below the average (hospital OR, 1.59; 95% CI, 1.39–1.77). Four hospitals had 30-day RSRRs statistically distinguishable from the overall average (1 hospital with 95% CI entirely below the mean [ie, better than average] and 3 hospitals with 95% CI entirely above the mean [ie, worse than average]). The distribution of hospital-specific SRRs ranged from 0.7 to 1.4 (IQR, 0.9–1.1) (Figure 1B). Sensitivity analysis after excluding patients who underwent PCI during or within 30 days before the TAVR hospitalization (n=1334) showed consistent results (correlation coefficient for hospital-specific SRRs before and after exclusion, r=0.98).

## Association of LOS, Discharge Disposition, and Hospital Characteristics With 30-Day RSRR Following TAVR

Differences in LOS and discharge disposition after TAVR accounted for only 15% of the observed variation in hospital 30-day RSRR.

A majority of the TAVR sites were large, private, teaching hospitals in metropolitan locations with no significant differences in hospital characteristics across quartiles of 30-day RSRR (Table 3). The median (IQR) hospital TAVR volume was 68 (41–117). TAVR hospitals in the lowest readmission quartile had higher median procedural volume (P=0.007). After adjusting for patient characteristics, there was no significant association between hospital bed size, control/ownership, teaching status, location, or TAVR volume and 30-day readmissions (Table 4).

Correlation Between 30-Day RSRRs Following TAVR and Other Procedures/ Diagnoses

There was statistically significant but weak correlation between hospital-specific 30-day RSRR after TAVR
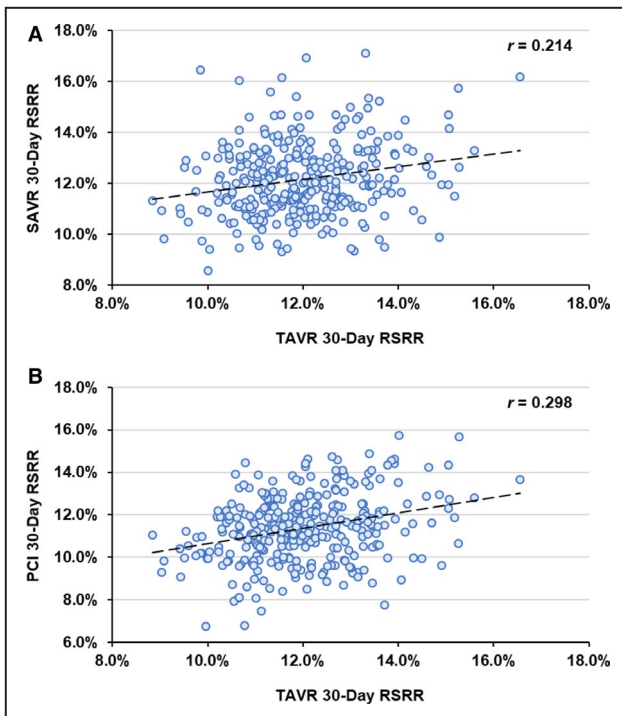
Figure 2. Correlation between 30-day RSRRs after TAVR and SAVR (A), and TAVR and PCI (B).
PCI indicates percutaneous coronary intervention; *r*, Pearson correlation coefficient; RSRR, risk-standardized readmission rate; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.

and that after SAVR (*r*=0.214; *P*<0.001), PCI (*r*=0.298; *P*<0.001), AMI (*r*=0.244; *P*<0.001), HF (*r*=0.272; *P*<0.001), and pneumonia (*r*=0.132; *P*=0.018) (Figures 2 and 3).

Hospital Variation in Causes of 30-Day Readmissions

Compared with the top 5% hospitals, the middle 90% and bottom 5% hospitals had a lower proportion of cardiac readmissions (especially for conduction disorders and dysrhythmias) and higher proportion of noncardiac readmissions (especially for gastrointestinal, renal, and endocrine causes) (Table 5; Figure 4).

DISCUSSION

In this analysis of 27 091 TAVR procedures performed across 325 hospitals in the United States, we report several important findings. First, we found significant between-hospital variation in 30-day RSRR following TAVR. Second, differences in LOS and discharge disposition accounted for only 15% of the observed variation in hospital 30-day RSRR after TAVR. Third, there was no significant association between hospital

characteristics (bed size, control/ownership, teaching status, location, and TAVR volume) and 30-day readmission rates. Fourth, there was statistically significant but weak correlation between 30-day RSRR after TAVR and that after other cardiovascular procedures (SAVR and PCI) and HRRP target conditions (AMI, HF, and pneumonia). Finally, causes of 30-day readmission varied across hospitals, with noncardiac readmissions being more common at the bottom 5% hospitals (ie, those with the highest RSRRs).

Thirty-day all-cause readmission rates after TAVR have ranged from 16.0% to 20.9% in previous studies.[3–5] Despite stringent patient selection criteria and standardized procedural techniques, there remains significant hospital variation in clinical outcomes of TAVR.[8–10] However, data on hospital variation in 30-day readmission rates after TAVR are limited. In a study of Medicare fee-for-service beneficiaries who underwent TAVR between January 2011 and December 2013, the median (IQR) 30-day RSRR was 20.9% (20.2%–22.1%), with a range of 17.1% to 24.4%.[4] For an individual patient, the between-hospital variation translated to 40% higher odds of 30-day readmission for a patient undergoing TAVR at a hospital 1 SD above the national average compared with undergoing TAVR at a hospital 1 SD below (hospital OR, 1.40; 95% CI, 1.37–1.44).[4] A recent analysis from the NRD demonstrated significant decrease in 30-day readmission rates after TAVR from 17% in 2012 to 12% in 2016.[7] Our current findings suggest that despite a decline in 30-day readmission rates after TAVR over the past several years, there remains substantial variation in 30-day RSRR across hospitals after adjusting for differences in patient characteristics.

The reasons underlying hospital variation in 30-day readmissions after TAVR remain unknown. Prior studies have identified patient-level factors including comorbidities, in-hospital complications, LOS, and discharge disposition as independent predictors of 30-day readmissions following TAVR.[3,18] In our study, only 15% of the observed variation in hospital 30-day RSRR was attributable to differences in LOS and discharge disposition. Focusing on patient-level factors may provide an incomplete picture of readmission risk at the hospital level, and hospital characteristics such as larger size, teaching status, and safety net hospital status have been shown to be associated with worse performance on the CMS hospital-wide readmission metric.[19,20] However, in the current study, we found no significant association of hospital characteristics such as bed size, control/ownership, teaching status, and location with 30-day readmission rates after TAVR. Similarly, although a prior study found an inverse association between hospital TAVR volume and 30-day readmission rates, no such relationship was observed in the current study, which is likely attributable to an
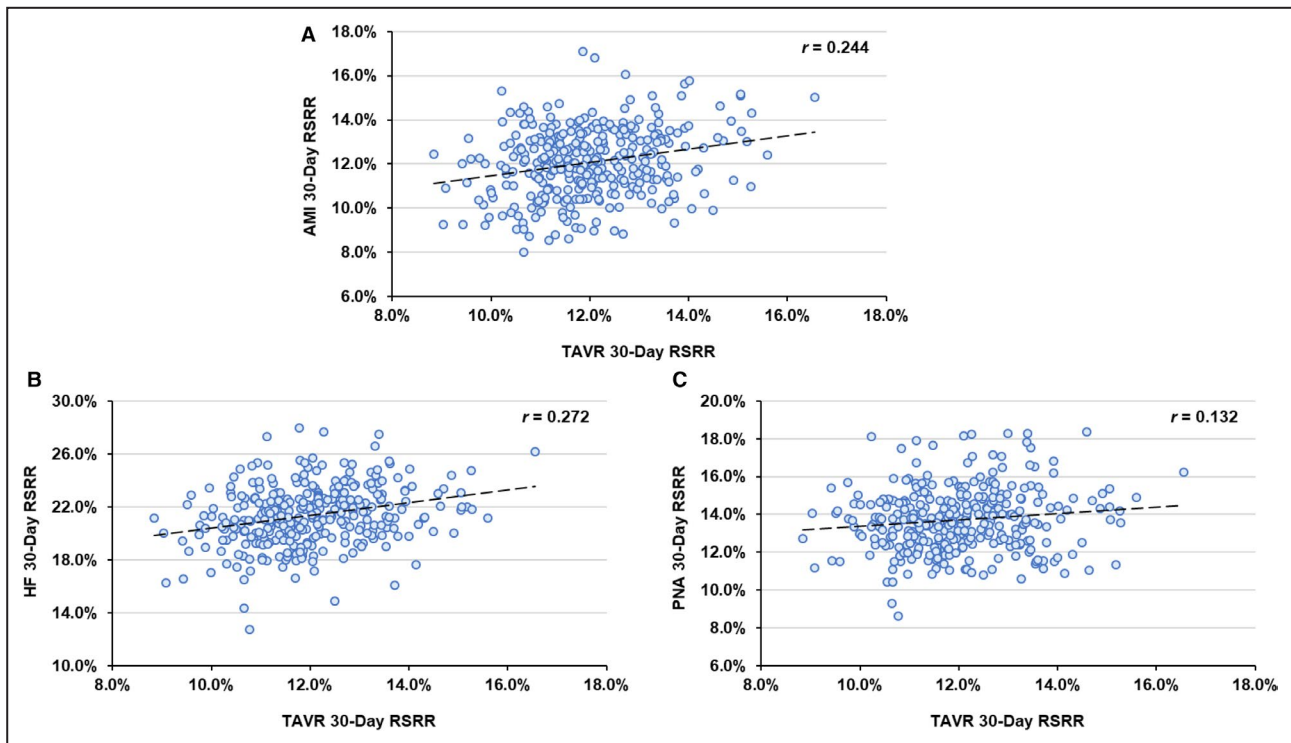
Figure 3. Correlation between 30-day RSRRs after TAVR and AMI (A), TAVR and HF (B), and TAVR and pneumonia (C).
AMI indicates acute myocardial infarction; HF, heart failure; *r*, Pearson correlation coefficient; RSRR, risk-standardized readmission rate; TAVR, transcatheter aortic valve replacement.

overall decline in readmission rates and increase in hospital TAVR volumes over the past few years.[7,21,22] Recent studies have also demonstrated a lack of association between hospital SAVR and PCI volumes with 30-day readmissions for TAVR.[23,24]

There is considerable overlap in hospital infrastructure, personnel, and processes of care involved in the management of patients undergoing SAVR, TAVR, or PCI. Similarly, the HRRP has led hospitals to implement a variety of interventions, such as arranging follow-up appointments before discharge, medication reconciliation, partnering with community physicians and local hospitals, and assigning staff to follow up on test results that return after the patient is discharged, to reduce readmissions for target conditions.[25] Services specific to readmissions, such as discharge planning, medication reconciliation, care coordination, and discharge communication, are often hospital-wide processes. RSRRs for AMI, HF, and pneumonia are moderately correlated with each other within hospitals (r=0.32–0.47; $P<0.001$), suggesting that that there may be common hospital-wide factors influencing readmission rates.[26] However, in the current study we found statistically significant but weak correlation between 30-day RSRR after TAVR and that after SAVR and PCI, AMI, HF, and pneumonia (r=0.132–0.298; $P<0.001$) within

hospitals. The correlation was weakest for TAVR and pneumonia suggesting that hospital-wide practices may influence readmission rates even less so for unrelated than related conditions.

Another important finding of our study is the variation in causes of 30-day readmissions after TAVR across hospitals. Thirty-day readmissions at the top 5% hospitals (ie, those with the lowest RSRRs) were more likely to be for cardiac causes, especially conduction disorders and dysrhythmias. This may reflect a trend toward early discharge after TAVR, and is consistent with findings from a recent study that showed an increase in the proportion of permanent pacemaker implantations during a subsequent hospitalization after the index TAVR.[27] On the contrary, the bottom 5% hospitals (ie, those with the highest RSRRs) had a higher proportion of noncardiac readmissions compared with the top 5% hospitals. Whether this is related to differences in patient characteristics, postdischarge care pathways, or "threshold" to readmit patients who have recently undergone a cardiac procedure warrants further investigation.

Our findings have several important implications for decreasing readmissions and improving quality of care for TAVR. First, despite a decline in 30-day readmission rates after TAVR, there remains substantial variation in 30-day RSRR across hospitals. Since

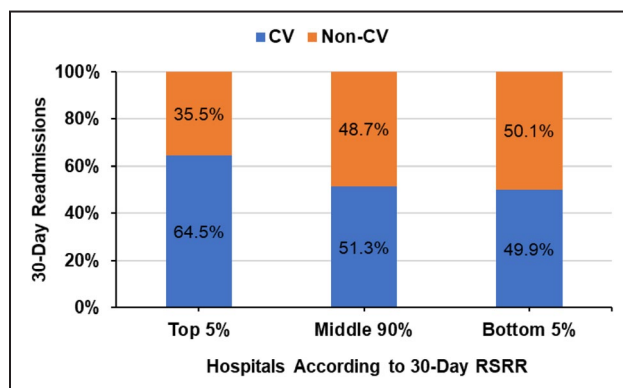**Table 5. Hospital Variation in Causes of 30-Day Readmission After TAVR**

Causes of 30-Day Readmission	Overall (n=3238)	Top 5% Hospitals (n=166)	Middle 90% Hospitals (n=2719)	Bottom 5% Hospitals (n=353)	P Value
Cardiovascular, n (%)	1677 (51.8)	107 (64.5)	1394 (51.3)	176 (49.9)	0.003
Heart failure	619 (19.1)	33 (19.9)	520 (19.1)	66 (18.7)	0.95
Complications of procedure/device	311 (9.6)	19 (11.4)	264 (9.7)	28 (7.9)	0.40
Conduction disorders	224 (6.9)	22 (13.3)	179 (6.6)	23 (6.5)	0.004
Dysrhythmias	192 (5.9)	17 (10.2)	149 (5.5)	26 (7.4)	0.020
CAD/chest pain	61 (1.9)	<10 (0.6)	57 (2.1)	<10 (0.8)	0.17
Acute myocardial infarction	63 (1.9)	<10 (1.8)	54 (2.0)	<10 (1.7)	0.96
Syncope	39 (1.2)	<10 (1.8)	32 (1.2)	<10 (1.1)	0.69
Peri/myo/endocarditis	27 (0.8)	<10 (1.2)	21 (0.8)	<10 (1.1)	0.45
Valve disorders	18 (0.6)	<10 (1.8)	14 (0.5)	<10 (0.3)	0.11
Other	123 (3.8)	<10 (2.4)	104 (3.8)	15 (4.2)	0.58
Noncardiovascular, n (%)	1561 (48.2)	59 (35.5)	1325 (48.7)	177 (50.1)	0.003
Infection	328 (10.1)	13 (7.8)	278 (10.2)	37 (10.5)	0.59
Respiratory	252 (7.8)	10 (6.0)	219 (8.1)	23 (6.5)	0.41
Bleeding	180 (5.6)	<10 (3.0)	157 (5.8)	18 (5.1)	0.30
Gastrointestinal	179 (5.5)	<10 (1.8)	151 (5.6)	25 (7.1)	0.048
Stroke/TIA	133 (4.1)	<10 (3.6)	113 (4.2)	14 (4.0)	0.93
Injury/Poisoning	107 (3.3)	<10 (1.8)	94 (3.5)	<10 (2.8)	0.45
Neuropsychiatric	97 (3.0)	<10 (4.8)	81 (3.0)	8 (2.3)	0.27
Renal	98 (3.0)	<10 (1.8)	76 (2.8)	19 (5.4)	0.018
Endocrine	75 (2.3)	<10 (1.2)	58 (2.1)	15 (4.2)	0.045
Hematology-Oncology	65 (2.0)	<10 (3.0)	55 (2.0)	<10 (1.4)	0.46
Other	50 (1.5)	<10 (1.2)	45 (1.7)	<10 (0.8)	0.59

CAD indicates coronary artery disease; TAVR, transcatheter aortic valve replacement; and TIA, transient ischemic attack.

unplanned readmissions are associated with increased healthcare costs, hospitals with 30-day RSRR above the national average may benefit from interventions to lower readmissions and costs.[2,3,28] Second, the lack of association of hospital characteristics such as bed size, control/ownership, teaching status, and location with 30-day RSRR after TAVR suggests that other hospital attributes that are specific to TAVR (eg, availability of stroke neurology, electrophysiology, and vascular surgery services) may be more important in influencing readmission rates potentially by improving postprocedural care, particularly of patients with complications. Third, the weak correlation between 30-day RSRR after TAVR and that after other related and unrelated procedures and diagnoses, as well as variation in causes of 30-day readmissions across hospitals suggests that in addition to the generic readmission reduction interventions, implementation of a targeted condition-specific program is likely needed to reduce readmissions after TAVR. Collectively, our findings highlight the need for future qualitative/mixed-method studies to identify the unique organizational practices that may be associated with decreased readmission rates following TAVR.[29]

Study Limitations

Our study has certain important limitations. First, although our analysis included 325 TAVR hospitals from 28 geographically dispersed states participating in the NRD, since this represents ≈60% of all TAVR sites in

Figure 4. Hospital variation in causes of 30-day readmissions following TAVR.
Proportion of 30-day cardiovascular and noncardiovascular readmissions in top 5% (lowest 30-day RSRR), middle 90%, and bottom 5% (highest 30-day RSRR) hospitals. CV indicates cardiovascular; and RSRR, risk-standardized readmission rates.

the United States in 2017, the possibility of selection bias cannot be eliminated.[30] Second, since readmissions across states cannot be tracked in the NRD, it is likely that readmission rates are underestimated. Third, the NRD contains only data on inpatient PCIs and does not include information on ≈11.9% of PCIs that occur in the outpatient setting.[31] Fourth, the NRD does not contain data on Society of Thoracic Surgeons score or EuroSCORE, laboratory and echocardiographic parameters, or procedural characteristics, which are collected in the Society of Thoracic Surgeons/American College of Cardiology Transcatheter Valve Therapy Registry. However, unlike the Transcatheter Valve Therapy Registry, the NRD offers the unique advantage of studying readmission rates after transcatheter valve therapies such as TAVR in the context of readmission rates for other procedures and diagnoses, as in the current study. Finally, since the NRD does not capture data on postdischarge mortality, we were unable to account for the competing risk between mortality and readmission.

CONCLUSIONS

Thirty-day readmission rates after TAVR vary significantly across hospitals even after adjusting for differences in patient characteristics. Differences in LOS and discharge disposition account for only 15% of the observed variation in hospital 30-day RSRR after TAVR. There is no significant association of hospital characteristics such as bed size, control/ownership, teaching status, location, and TAVR volume with 30-day readmission rates after TAVR. There is statistically significant but weak correlation between 30-day readmission rates after TAVR and those after other cardiovascular procedures (SAVR, PCI) and HRRP target conditions (AMI, HF, and pneumonia) within hospitals. Noncardiac readmissions are more common in hospitals with the highest RSRRs. Future qualitative/mixed-method studies are needed to determine the unique organizational practices that differentiate TAVR hospitals with readmission rates below and above the national average and to identify modifiable practices associated with decreased readmission rates.

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