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Original Article

Readmission Mortality After TAVR: The Combined Effect of Teaching Hospital Status and Cause of Readmission

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ABSTRACT

Background: Variability in transcatheter aortic valve replacement (TAVR) readmission rates highlights the importance of assessing post-discharge outcomes. Understanding how teaching hospital status and causes of readmission influence mortality could optimise post-TAVR care.

Methods: Using the National Readmissions Database, we identified 155,298 TAVR admissions from 2012 to 2020. We evaluated the interaction effect between teaching status and cause of readmission on readmission-related mortality through adjusted mixed-effects models.

Results: Overall, 18.9% of patients (n = 29,479) had a nonelective readmission within 90 days, with no significant difference between teaching and nonteaching hospitals (19.3% vs 18.9%; $P > 0.05$). Cardiac-related readmissions accounted for 42.7% of cases, while noncardiac readmissions made up 57.3%, with no differences observed in their distribution between teaching and nonteaching hospitals. The unadjusted 90-day readmission mortality rate was 3.8%, without significant differences between teaching and nonteaching hospitals (3.8% vs 4.1%; $P = 0.38$). A downward trend in nonelective readmission and readmission-related mortality rates was observed, regardless of teaching status. An interaction effect between teaching status and the cause of readmission was identified: Noncardiac readmissions to teaching hospitals were associated with increased odds of death (odds ratio [OR] 1.82, 95% confidence interval [CI] 1.59-2.07; $P < 0.001$) compared with nonteaching hospitals, whereas cardiac readmissions to teaching hospitals were associated with decreased odds of in-hospital mortality (OR 0.55, 95% CI 0.48-0.62; $P < 0.001$).

Conclusion: Our findings indicate a differential association between

RÉSUMÉ

Contexte : La variabilité des taux de réadmission pour un remplacement valvulaire aortique par cathéter (RVAC) souligne l'importance d'évaluer les résultats cliniques après la sortie de l'hôpital. Comprendre comment le statut d'hôpital universitaire avec fonction d'enseignement et les causes de réadmission influencent la mortalité pourrait optimiser les soins post-RVAC.

Méthodes : En utilisant la base de données nationale des réadmissions (NRD), nous avons identifié 155 298 admissions pour RVAC de 2012 à 2020. Nous avons évalué l'effet d'interaction entre le statut d'hôpital universitaire et la cause de la réadmission sur la mortalité liée à la réadmission au moyen de modèles à effets mixtes ajustés.

Résultats : Dans l'ensemble, 18,9 % des patients (n = 29 479) ont subi une réadmission non programmée dans les 90 jours, sans différence significative entre les hôpitaux universitaires et non universitaires (19,3 % vs 18,9 % ; $p > 0,05$). Les réadmissions pour cause cardiaque représentaient 42,7 % des cas, tandis que les réadmissions pour cause non cardiaque représentaient 57,3 %, sans qu'aucune différence n'ait été observée dans leur répartition entre les hôpitaux universitaires et les hôpitaux non universitaires. Le taux de mortalité non ajusté, à 90 jours, suite à une réadmission, était de 3,8 %, sans différence significative entre les hôpitaux universitaires et non universitaires (3,8 % vs 4,1 % ; $p = 0,38$). Une tendance à la baisse des taux de réadmission non planifiée et de mortalité liée à la réadmission a été observée, quel que soit le statut de l'hôpital. Un effet d'interaction entre le statut de l'hôpital et la cause de la réadmission a été identifié : les réadmissions non cardiaques dans les hôpitaux universitaires étaient associées à une augmentation du risque de décès

The Hospital Readmissions Reduction Program[1,2] put nonelective readmissions as a front-line metric of interest due to its association with poor outcomes and higher hospitalisation costs.[3] Although initially only some prevalent conditions were evaluated with the metric, it has been adopted to evaluate other health services over the past decade. For

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teaching hospital status and 90-day readmission mortality, contingent on the cause of readmission. Further research, including the use of metrics such as failure to rescue, is needed to better understand the relationship between patient-level variables and teaching hospital status.

(rapport de cotes [RC] 1,82, intervalle de confiance [IC] à 95 % 1,59-2,07 ; *p* < 0,001) par rapport aux hôpitaux non universitaires, tandis que les réadmissions cardiaques dans les hôpitaux universitaires étaient associées à une diminution du risque de mortalité à l'hôpital (RC 0,55, IC à 95 % 0,48-0,62 ; *p* < 0,001).

Conclusion : Nos résultats indiquent une association différentielle entre le statut d'hôpital universitaire et la mortalité à 90 jours, en fonction de la cause de la réadmission. D'autres recherches, y compris l'utilisation de mesures telles que l'échec des interventions de sauvetage, sont nécessaires pour mieux comprendre la relation entre les variables au niveau des patients et le statut d'hôpital universitaire.

example, a wealth of research has focused on understanding patient- and hospital-level characteristics associated with readmission rates after transcatheter aortic valve replacement (TAVR).[4-6]

Previous TAVR studies have reported 30-day readmission rates of around 20%,[7-9] where factors such as increasing number of comorbidities, transapical approach, and discharge to a skilled nursing facility have been described to be independent predictors of readmission. Even though we have observed a downward trend in all-cause readmission during the 2012-2016 period,[10] still there is a significant readmission variability among centres ranging from 0% to 50%.[7] Furthermore, readmission and mortality hazard are time and cause dependent, in which both cardiac and noncardiac causes of readmission occur at similar rates immediately after TAVR but after long-term follow up, noncardiac causes remain as the most common.[5,11]

Although TAVR mortality during index hospitalisation has reached relatively low numbers, its distribution after discharge is not negligible. Determining the impact of teaching hospital status on mortality during a 90-day readmission is important for 2 reasons. First, the literature has shown that mortality is highest during this window.[12] And second, hospital factors can be modifiable, in contrast to patients risk profiles.[13] In this regard, little is known on how teaching hospital status interacts with the cause of readmission after TAVR and its impact on mortality during a readmission. We therefore sought to determine the combined effect of teaching hospital status and the cause of nonelective readmission with readmission-related mortality after TAVR.

Methods

Data source

We used the 2012-2020 Nationwide Readmissions Database (NRD), a publicly available database of all-payer hospital inpatient stays in the US developed by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project (HCUP). The NRD is drawn from the State Inpatient Databases that contain reliable, verified patient linkage numbers that can be used to track a patient across hospitals within a state while adhering to strict privacy guidelines. The NRD includes all discharge records of patients treated in US community hospitals, excluding rehabilitation and long-term acute care facilities. Discharge weights are provided to obtain national estimates.

Study population and baseline characteristics

We used the International Classification of Diseases, 9th and 10th Editions, Clinical Modification (ICD) procedure codes to identify all hospital admissions with a TAVR procedure in patients aged $\geq$ 18 years. We excluded index cases after October 1 and the admission with in-hospital mortality during index cases to estimate 90-day readmission rate and readmission-related mortality. Only the first readmission was included for those with multiple readmissions. Baseline patient characteristics included were age, sex, primary expected payer, median household income, and relevant comorbidities. Hospital characteristics such as location and number of beds were also included. Comparative analyses were done according to the teaching hospital status.

Outcomes

Our primary end point was in-hospital mortality during a 90-day all-cause nonelective readmission. Readmissions were identified according to the methodology outlined by the HCUP. For patients who had multiple readmissions, only the first readmission was included. The primary diagnosis of each readmission record was reviewed and grouped into clinically meaningful categories to determine the main cause of readmission.

The causes of readmissions were classified as cardiac and noncardiac. Cardiac causes included heart failure, arrhythmias and conduction disorders, endocarditis, prosthesis-related mechanical complications, hypertension related, pericarditis, acute coronary syndromes, and other nonspecific cardiac diseases. Noncardiac causes included respiratory (including pneumonia), infection, bleeding, transient ischemic attack or stroke, renal, gastrointestinal, hematologic and neoplasms, endocrine and metabolic, neuropsychiatric, and others. Most of the ICD codes included in the "other" category within the noncardiac causes were related to trauma and osteomuscular diseases, nonspecific codes such as altered mental status, disorders of electrolyte and fluid balance, hypoglycemia, and syncope, among others. Diagnosis categories and the corresponding IICD codes are listed in Supplemental Table S1. Secondary outcomes examined were length of stay (LOS) and total hospital costs.

Statistical analysis

Baseline characteristics, in-hospital outcomes, and in-hospital complications were compared between teaching and nonteaching hospitals during a 90-day readmission with the

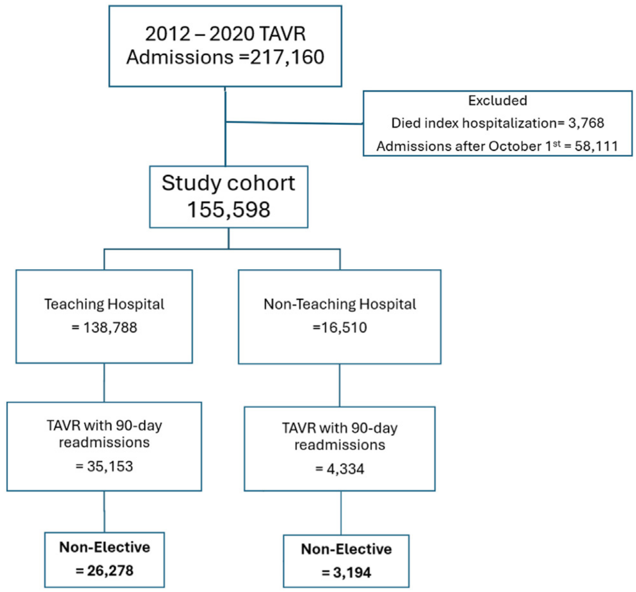

Figure 1. Consort-like diagram illustrating patients included and excluded from the study according to hospital's teaching status and nonelective readmission at 90 days. TAVR, transcatheter aortic valve replacement.

use of nonparametric testing. Categoric variables are expressed as percentages and continuous variables as median with interquartile range (IQR). Mixed-effects logistic regression was used to identify predictors of 90-day readmission. Hospitals were added as a random-effect term to the model. Variables with a P value < 0.2 on univariable analysis were entered into a multivariable regression model to identify independent predictors of mortality during a 90-day readmission. An alpha level of 0.05 determined statistical significance. Statistical analysis was performed using SAS version 9.4 software (SAS Institute).

Results

We identified 155,298 admissions where TAVR was the primary procedure, with 89.4% (n = 138,788) performed in teaching hospitals and 10.6% (n = 16,510) in nonteaching hospitals (Fig. 1). Overall, 18.9% of admissions (n = 29,479) had a nonelective readmission within 90 days, with higher rates in teaching hospitals than in nonteaching hospitals (23.6% vs 21.5%; $P < 0.001$). Of these readmissions, 61.5% (n = 18,133) occurred within the first 30 days after discharge, with teaching hospitals having a higher proportion of early readmissions than nonteaching hospitals (61.7% vs 59.7%; $P = 0.02$).

The median age of patients with a nonelective 90-day readmission was 82 years (IQR 75-87 years), 45.9% (n = 13,521) were women, and the majority underwent transfemoral access (93.3% vs 4.7% for apical access) (Table 1). Women accounted for a larger proportion of readmissions at teaching hospitals compared with nonteaching hospitals (46.1% vs 43.8%; $P < 0.01$).

Trend analysis showed an overall decrease in nonelective 90-day readmission rates, dropping from 25.2% in 2012 to 15.2% in 2020 ($P < 0.001$). This trend was consistent for both teaching and nonteaching hospitals, with rates declining from 25.4% to 15.3% in teaching hospitals and from 22.7% to 16.3% in nonteaching hospitals ($P < 0.001$) (Fig. 2).

Cause of readmission

Overall, 42.7% of nonelective readmissions (n = 12,593) were cardiac related, and 57.3% (n = 16,879) were noncardiac readmissions. No differences were observed in the distribution of cardiac (42.1% vs 42.8%; $P = 0.84$) and noncardiac (57.9% vs 57.2%; $P = 0.47$) causes of readmission between teaching and nonteaching hospitals. Regarding cardiac readmission causes, the most common group was heart failure (17.8%; n = 5254), followed by "cardiac nonspecific" causes (10.5%; n = 3101), which included codes such as valvular disorders and atherosclerotic heart disease without angina, among others (Supplemental Table S2). The most frequent category of noncardiac readmissions was "other," accounting for 25.0% (n = 7356) of cases, followed by infectious diagnoses, which made up 12.8% (n = 3768). We observed a significantly higher proportion of arrhythmia-related readmissions and acute coronary syndromes in nonteaching hospitals than in teaching hospitals, with rates of 9.5% vs 7.8% ($P < 0.01$) and 3.9% vs 2.9% ($P = 0.01$), respectively.

Resource utilisation

The median length of stay was 4 days (IQR 2-9 days), with readmission stays being shorter in nonteaching hospitals than in teaching hospitals (median 3 vs 4 days; $P < 0.01$). The rate of redo TAVR was 7.3%, with a higher proportion occurring in teaching hospitals than in nonteaching hospitals (7.5% vs 6.3%; $P = 0.01$) (Table 2). Surgical AVR was extremely uncommon during nonelective readmissions occurring within the first 90 days after discharge.

Regarding hospitalisation costs, the median cost of readmission was $11,000 (IQR $6,100-$22,000) for the total

Table 1. Baseline characteristics of readmitted patients after transcatheter aortic valve replacement (TAVR) by hospital teaching status

Variable	Total (n = 29,472)	Non−teaching hospital (n = 3194)	Teaching hospital (n = 26,278)	*P* value
Age, y	82.0 (75.0-87.0)	82.0 (76.0-87.0)	82.0 (75.0-87.0)	0.24
Female	45.9 (13,521)	43.8 (1398)	46.1 (12,123)	0.01
Transapical access	4.7 (1381)	3.8 (122)	4.8 (1259)	0.01
TAVR discharge location				< 0.001
Routine	48.5 (14,282)	53.9 (1721)	47.8 (12,561)	
Short-term hospital	0.5 (148)	0.4 (12)	0. 5 (136)	
SNF, ICF, or other	21.5 (6,343)	19.8 (631)	21.7 (5712)	
Home health care	29.4 (8,667)	25.8 (824)	29.8 (7843)	
Insurance				0.63
Medicare	91.3 (26,898)	91.8 (2933)	91.2 (23,965)	
Medicaid	1.5 (432)	1.6 (51)	1.4 (381)	
Private	5.4 (1580)	4.9 (156)	5.4 (1424)	
Comorbidities				
Diabetes mellitus	43.9 (12,887)	42.6 (1361)	43.9 (11,526)	0.17
Dyslipidemia	67.9 (20,022)	68.3 (2180)	67.9 (17,842)	0.68
Hypertension	88.8 (26,177)	88.7 (2834)	88.8 (23,343)	0.86
CAD	72.2 (21,288)	72.6 (2318)	72.2 (18,970)	0.64
Congestive heart failure	79.6 (21,288)	79.3 (2533)	79.7 (20,941)	0.60
Cerebral vascular disease	11.9 (3507)	12.7 (405)	11.8 (3102)	0.14
PVD	19.5 (5757)	18.7 (576)	19.6 (5,161)	0.18
COPD	27.8 (8203)	28.6 (913)	27.7 (7290)	0.31
Chronic kidney disease	44.0 (12,963)	43.3 (1383)	44.1 (11,580)	0.40
County of the hospital				< 0.001
Large metropolitan area	66.1 (19,476)	46.2 (1476)	68.5 (18,000)	
Small metropolitan area	33.9 (9996)	53.8 (1718)	31.5 (8278)	
Hospital size by no. of beds				< 0.001
Small	4.3 (1260)	5.6 (179)	4.1 (1081)	
Medium	21.3 (6269)	11.3 (361)	22.5 (5908)	
Large	74.5 (21,943)	83.1 (2654)	73.4 (19,289)	

Values are median (interquartile range) or % (n).

CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; ICF, intermediate care facility; PVD, peripheral vascular disease; SNF, skilled nursing facility.

sample, with higher costs observed in teaching hospitals (median $11,200, IQR $6,100-$22,300) than in nonteaching hospitals (median $9,060, IQR $5,600-$20,200) ($P < 0.001$).

Readmission-related in-hospital mortality

Crude 90-day readmission mortality was 3.8% (n = 1117) during the study period, without difference between teaching and nonteaching hospitals (3.8% vs 4.1%; $P = 0.38$). We observed a significant downward trend in readmission-related mortality from 6.0% in 2012 to 4.0% in 2020. This trend was again consistent for both teaching and nonteaching hospitals, with rates declining from 6.5% to 3.7% in nonteaching hospitals and from 6.2% to 4.2% in teaching hospitals ($P < 0.05$) (Fig. 2).

Table 2. In-hospital outcomes for 90-day nonelective readmissions by teaching status

Variable	Total (n = 29,472)	Non−teaching hospital (n = 3194)	Teaching hospital (n = 26,278)	*P* value
30-day readmissions	61.5 (18,133)	59.7 (1908)	61.7 (16,223)	0.02
Mortality	2.2 (644)	2.2 (71)	2.3 (573)	0.87
Cost, $	12,200 (6410-24,900)	10,900 (6000-21,600)	12,300 (6500-25,210)	< 0.001
90-day readmissions				
In-hospital mortality	3.8 (1117)	4.1 (130)	3.8 (987)	0.38
Redo TAVR	7.3 (2158)	6.3 (200)	7.5 (1958)	0.01
Surgical intervention	0.03 (5)	0.00%	0.04 (5)	0.45
Cost, $	11,030 (6140-24,800)	10,300 (5650-21,600)	12,330 (6590-25,200)	< .001
Length of stay, d	4 (2-9)	3 (2-8)	4 (2-10)	< .001
Associated secondary diagnosis				
Cardiac arrhythmia	35.5 (10,450)	31.4 (1003)	36.1 (9447)	< .001
Pneumonia	3.5 (1,040)	3.8 (120)	3.5 (920)	0.45
Respiratory failure	2.9 (853)	3.0 (96)	2.9 (757)	0.69
Acute kidney injury	18.0 (5302)	16.9 (540)	18.1 (4762)	0.09
Urinary tract infection	9.8 (2880)	8.7 (278)	9.9 (602)	0.03
Stroke	1.1 (314)	0.7 (22)	1.1 (292)	0.02
Sepsis	1.2 (349)	1.2 (39)	1.2 (310)	0.83
Hemorrhage	19.1 (5619)	14.7 (470)	19.6 (5149)	< 0.001

Values are % (n) or median (interquartile range).

TAVR, transcatheter aortic valve replacement.

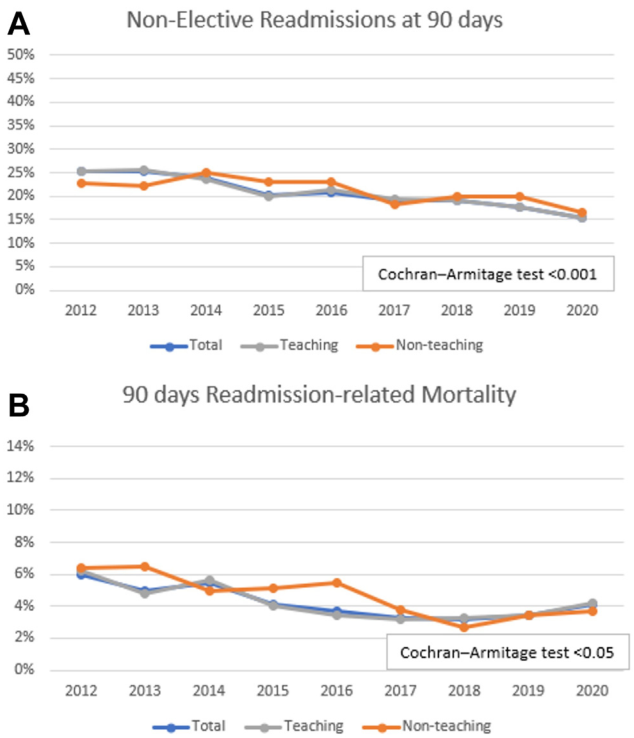

Figure 2. Trend analysis stratified by teaching status. (**A**) Nonelective 90-day readmissions after TAVR from 2012 to 2020. (**B**) 90-day readmission-related mortality after TAVR from 2012 to 2020. Analyses are stratified by overall cohort (**blue**), teaching hospitals (**gray**), and nonteaching hospitals (**orange**). A significant reduction in both nonelective 90-day readmission and mortality rates during readmission is observed (Cochran-Armitage test: $P < 0.05$).

The crude mortality rate for cardiac readmissions was 2.4% (n = 298), compared with 4.8% (n = 819) for noncardiac readmissions. This corresponds to 53% decreased odds of death for cardiac-related readmissions compared with noncardiac causes (OR 0.47, 95% CI 0.41-0.54; $P < 0.001$). However, the multivariable analysis revealed an interaction effect between the cause of readmission and the teaching status of the hospital. Cardiac readmissions to teaching hospitals were associated with a lower likelihood of death (OR 0.54, 95% CI 0.47-0.62; $P < 0.001$) compared with nonteaching hospitals. In contrast, noncardiac readmissions were associated with increased odds of death in teaching hospitals (OR 1.81, 95% CI 1.57-2.06; $P < 0.001$) after adjusting for other covariates (Table 3 and Fig. 3). Regarding specific causes of readmission, endocarditis (OR 4.7, 95% CI 1.39-21.7; $P < 0.001$), respiratory problems (OR 2.5, 95% CI 1.36-4.69; $P < 0.001$), and infections (OR 3.1, 95% CI 1.62-5.58; $P < 0.001$) were associated with significantly increased odds of death during readmission (Supplemental Table S3).

Discussion

In this analysis, we highlight several key findings regarding mortality and resource utilisation during readmissions at 90 days following TAVR. Firstly, we observed a significant interaction effect between the cause of readmission and the hospital's teaching status. This means that the effect of the hospital's teaching status on mortality rates varies depending on whether the readmission was due to a cardiac or noncardiac cause. Specifically, noncardiac readmissions to teaching hospitals were associated with increased odds of in-hospital mortality, whereas cardiac-related readmissions to teaching hospitals were linked to decreased odds of death. However, resource utilisation during readmissions was notably higher in teaching hospitals, as reflected by longer lengths of stay and increased costs. Finally, disease-specific analyses demonstrated significantly higher mortality rates associated with readmission related to endocarditis, respiratory problems, and infections.

Whereas previous studies did not show significant differences in clinical outcomes during index TAVR hospitalisations,[14] our findings suggest that hospital factors may play a critical role in outcomes during readmissions. The observed differences in mortality between teaching and nonteaching hospitals could be influenced by various confounding factors,[15] such as the complexity and risk profile of patients typically treated at teaching hospitals.[16] This might be particularly relevant for noncardiac readmissions, for which higher mortality may not reflect the quality of care but rather the baseline clinical condition. Selection bias could explain the differential mortality observed in teaching hospitals during a readmission, because these patients may already be at a heightened risk of adverse outcomes. For example, severely ill patients are often transferred from nonteaching institutions to teaching hospitals.[17,18] Moreover, frailty is a prevalent factor in TAVR patients and plays a critical role determining readmissions and in-hospital mortality.[19,20]

The ORs in this study indicate that the relationship between teaching status and mortality varies depending on the

Table 3. Mixed-effects logistic regression evaluating combined effect of teaching status and cause of nonelective readmissions on mortality during 90-day readmissions

Effect	Point estimate	95% CI	*P* value
Cardiac readmission, nonteaching hospital (ref) vs teaching	0.54	0.47-0.62	< 0.01
Noncardiac readmission, nonteaching hospital (ref) vs teaching	1.81	1.57-2.06	< 0.01
Age	1.01	1.01-1.02	0.02
Discharge location—home as reference			
Transfer to short-term hospital	2.13	1.15-3.92	0.01
Skilled nursing facility or intermediate care facility	1.68	1.43-1.98	< 0.01
NCHS urban-rural counties classification—central metro area as reference			
250,000-999,999 population	1.25	1.05-1.49	0.01
Rural	1.34	1.10-1.77	0.02
Secondary diagnosis			
Diabetes mellitus	0.89	0.75-1.06	0.09
Hypertension	0.78	0.6-1.0	0.04
Cardiac arrhythmia	1.14	1.02-1.31	0.04
Peripheral artery disease	1.41	1.1-1.7	< 0.01
Acute kidney failure	1.36	1.16-1.58	< 0.01
Heart failure	1.17	1.02-1.31	< 0.01
Length of stay	1.02	1.01-1.03	< 0.01

Transapical access also was evaluated and did not show association with mortality during a nonelective readmission.

CI, confidence interval; NCHS, National Center for Health Statistics.

cause of readmission. Nevertheless, without proper risk standardisation, these ORs should be viewed as indicative of associations rather than definitive causal relationships. The findings suggest that while teaching hospitals may excel in managing cardiac-related readmissions, they might face challenges with noncardiac cases, potentially owing to patient complexity or systemic factors within the hospital.[21] This underscores the need for further analysis that adjusts for patient risk factors and comorbidities to determine whether the observed differences are attributable to the hospital's teaching status or underlying patient characteristics. Despite these limitations, the study's findings can still inform health care leaders by highlighting areas for targeted interventions, such as improving the management of noncardiac conditions or enhancing care coordination for complex patients within teaching hospitals.

Early reports from the Transcatheter Valve Therapy Registry, including data from 2011-2013, demonstrated global mortality rates after TAVR of 16.7% at 6 months and 23.7% at 1 year,[22] with significant improvement in 1-year mortality after TAVR, particularly among high-risk patients from 21.8% in 2014 to 16.4% in 2018 ($P = 0.001$).[23] However, previous reports have not been able to show a significant downward trend in all-cause readmission mortality.[8] Building on these existing data, our findings confirm reductions in nonelective 90-day readmission rates and highlight decreasing readmission-related mortality rates over the study period, consistent across both teaching and nonteaching hospitals. This trend was consistent for both teaching and nonteaching hospitals. These trends can be attributed to advances in TAVR technology, such as enhanced valve designs and improved delivery systems, as well as the increasing experience and knowledge gained from performing TAVR procedures. This cumulative knowledge has likely led to better patient selection, risk stratification, and standardisation of multidisciplinary heart teams in TAVR programs.[24,25] Moreover, the expanding use of TAVR in lower-risk patient populations—who typically have fewer comorbidities and better overall health— may have contributed to these outcomes.[26]

These results have important implications for health care systems. First, with a remaining 19% of nonelective readmissions, this finding emphasises the need for enhanced postprocedural care and follow-up strategies, such as close monitoring, timely interventions, medication management, and patient education, to mitigate the risk of nonelective readmissions and improve patient outcomes. In addition, our analysis suggests the importance of continuing stratified evaluations that consider macrosystem factors, such as the teaching status of the hospital and the causes of readmission, when assessing patient outcomes and developing targeted interventions. This approach acknowledges the presence of confounders and highlights the need for further research to better understand these associations. Future studies should delve into these aspects to uncover the underlying mechanisms driving variations in mortality and identify specific factors, for example, the impact of fragmented care on failure to rescue and variability in microsystem characteristics among TAVR programs. These insights will be crucial for improving patient outcomes and guiding hospital policies.

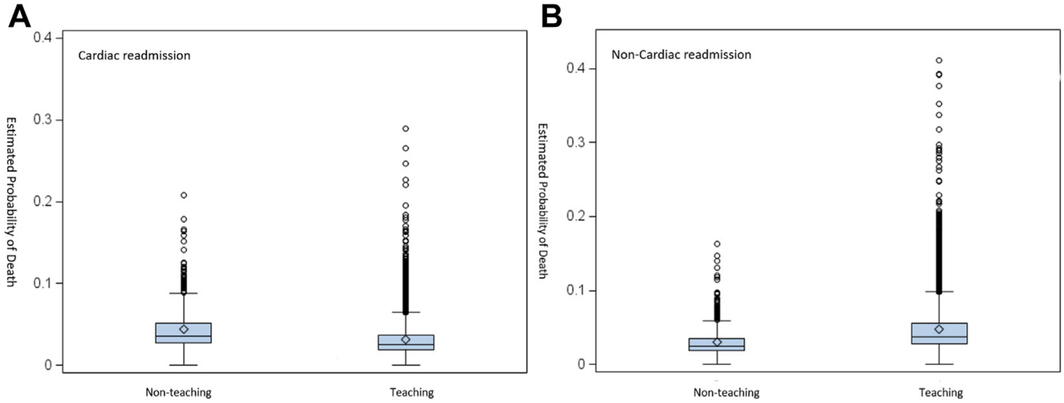

Figure 3. Box plots comparing the estimated probability of death during 90-day readmissions for (**A**) cardiac and (**B**) noncardiac causes, stratified by teaching and nonteaching hospitals.

This study has several limitations, besides those already mentioned, that should be considered when interpreting the findings. First, although our results suggest an association between teaching hospital status and higher odds of mortality during noncardiac readmissions, the retrospective design of the study inherently limits the ability to establish causal relationships. Further research is necessary to confirm these findings and explore the underlying mechanisms, particularly how factors such as referral patterns and institutional resources may contribute to the observed differences in outcomes. Second, our analysis relied on administrative databases, which, although comprehensive and widely used in health services research, have inherent limitations due to the lack of detailed clinical information about the specific conditions leading to readmissions. For example, variables such as patient complexity, frailty, nutritional status, functional capacity, and social determinants of health are not captured. Furthermore, administrative databases rely on coding practices that may vary across institutions and could lead to misclassification or underreporting of certain conditions, further limiting the precision of the analysis.

The observed differential outcomes for cardiac and noncardiac readmissions in teaching hospitals should be viewed as hypothesis generating rather than confirmatory. The lack of detailed data regarding care models and resource utilisation beyond macrosystem factors available in the HCUP databases introduces uncertainty and limits definitive conclusions. Although plausible explanations such as specialised cardiac care, referral patterns, and patient complexity may account for these findings, they remain speculative. This study underscores the need for further prospective research to validate or refute these observations, explore the underlying mechanisms, and examine how differences in care models, team composition, and resource allocation between teaching and nonteaching hospitals contribute to these outcomes. Such investigations could provide actionable insights to optimise care for both cardiac and noncardiac readmissions across diverse healthcare settings.

Conclusion

This study provides valuable insights into the outcomes of nonelective readmissions within 90 days of TAVR and the potential influence of teaching hospital status on these outcomes, depending on the cause of readmission. The findings suggest that teaching hospitals may have lower mortality rates for cardiac-related readmissions compared with nonteaching hospitals. Conversely, noncardiac readmissions were associated with higher mortality rates in teaching hospitals, underscoring the need for further investigation into the factors driving this disparity. Despite its limitations, this study highlights the importance of characterising in-hospital resource utilisation and optimising perioperative care programs to reduce the risk of nonelective readmissions and mortality. Future research should focus on identifying the microsystem factors contributing to these observed differences, with the goal of improving patient outcomes in both teaching and nonteaching hospital settings.

Ethics Statement

This research was determined to be exempt research with a waiver of informed consent from the Institutional Review Board of the University of Pittsburgh (STUDY18120143).

Patient Consent

The authors confirm that patient consent was not applicable to this article. This was a retrospective analysis using an administrative public database using de-identified data; therefore, the institutional review board did not require consent from the patient.

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Disclosures

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References

1. Zhang DJ, Gurvich I, van Mieghem JA, et al. Hospital Readmissions Reduction Program: an economic and operational analysis. Manage Sci 2016;62:3351-71.
2. McIlvennan CK, Eapen ZJ, Allen LA. Hospital Readmissions Reduction Program. Circulation 2015;131:1796-803.
3. Khera R, Krumholz HM. Effects of the Hospital Readmissions Reduction Program. Circ Cardiovasc Qual Outcomes 2018;11:12.
4. Nombela-Franco L, del Trigo M, Morrison-Polo G, et al. Incidence, causes, and predictors of early (≤30 days) and late unplanned hospital readmissions after transcatheter aortic valve replacement. JACC Cardiovasc Interv 2015;8:1748-57.
5. Senussi MH, Schindler J, Sultan I, et al. Long term mortality and readmissions after transcatheter aortic valve replacement. Cardiovasc Diagn Ther 2021;11:1002-12.
6. Goldsweig A, Aronow HD. Identifying patients likely to be readmitted after transcatheter aortic valve replacement. Heart 2020;106:256-60.
7. Kolte D, Khera S, Sardar MR, et al. Thirty-day readmissions after transcatheter aortic valve replacement in the United States. Circ Cardiovasc Interv 2017;10:e004472.
8. Zahid S, Din MTU, Khan MZ, et al. Trends, predictors, and outcomes of 30-day readmission with heart failure after transcatheter aortic valve replacement: insights from the US Nationwide Readmission Database. J Am Heart Assoc 2022;11:e024890.
9. Aranda-Michel E, Kilner D, Toma C, et al. A readmission risk score for transcatheter aortic valve replacement: an analysis of 200,000 patients. Cardiovascular Revascularization Medicine 2023;53:8-12.
10. Arora S, Strassle PD, Hendrickson MJ, et al. Temporal trends in readmissions after transcatheter aortic valve replacement. Eur Heart J 2020;41(suppl 2):ehaa946.1928.
11. Bianco V, Kilic A, Gleason TG, et al. Long-term hospital readmissions after surgical vs transcatheter aortic valve replacement. Ann Thorac Surg 2019;108:1146-52.
12. Hirji S, McGurk S, Kiehm S, et al. Utility of 90-day mortality vs 30-day mortality as a quality metric for transcatheter and surgical aortic valve replacement outcomes. JAMA Cardiol 2020;5:156.
13. Malik AH, Yandrapalli S, Zaid S, et al. Impact of frailty on mortality, readmissions, and resource utilization after TAVI. Am J Cardiol 2020;127:120-7.

14. Hasan I, Brown JA, Aranda-Michel E, et al. Outcomes of transcatheter aortic valve replacement at teaching versus nonteaching hospitals. J Card Surg 2022;37:3550-5.

15. Burke LG, Frakt AB, Khullar D, Orav EJ, Jha AK. Association between teaching status and mortality in US hospitals. JAMA 2017;317:2105.

16. Silber JH. Hospital teaching intensity, patient race, and surgical outcomes. Arch Surg 2009;144:113.

17. Silber JH, Rosenbaum PR, Niknam BA, et al. Comparing outcomes and costs of medical patients treated at major teaching and nonteaching hospitals: a national matched analysis. J Gen Intern Med 2020;35:743-52.

18. Shahian DM, Liu X, Meyer GS, Normand SLT. Comparing teaching versus nonteaching hospitals. Acad Med 2014;89:94-106.

19. Abugroun A, Daoud H, Hallak O, Abdel-Rahman ME, Klein LW. Frailty predicts adverse outcomes in older patients undergoing transcatheter aortic valve replacement (TAVR): from the National Inpatient Sample. Cardiovasc Revasc Med 2022;34:56-60.

20. Kiani S, Stebbins A, Thourani VH, et al; STS/ACC TVT Registry. The effect and relationship of frailty indices on survival after transcatheter aortic valve replacement. JACC Cardiovasc Interv 2020;13:219-31.

21. Shahian DM, Nordberg P, Meyer GS, et al. Contemporary performance of U.S. teaching and nonteaching hospitals. Acad Med 2012;87:701-8.

22. Holmes DR, Brennan JM, Rumsfeld JS, et al. Clinical outcomes at 1 year following transcatheter aortic valve replacement. JAMA 2015;313:1019.

23. Carroll J, Mack M, Vemulapalli S, et al. STS-ACC TVT Registry of transcatheter aortic valve replacement. J Am Coll Cardiol 2020;76:2492-516.

24. Faroux L, Nombela-Franco L, Têtu-Couture M, et al. Unplanned hospital readmissions after transcatheter aortic valve replacement in the era of new-generation devices. J Invasive Cardiol 2022;34:e299-309.

25. Nishimura RA, Otto CM, Bonow RO, et al. 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation 2017;135:e1159-95.

26. Mack MJ, Leon MB, Thourani VH, et al; PARTNER 3 Investigators. Transcatheter aortic-valve replacement with a balloon-expandable valve in low-risk patients. N Engl J Med 2019;380:1695-705.

Supplementary Material

To access the supplementary material accompanying this article, visit the online version of the *Canadian Journal of Cardiology* at www.onlinecjc.ca and at https://doi.org/10.1016/j.cjco.2024.12.014.