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ORIGINAL RESEARCH

Impact of Transcatheter Aortic Valve Replacement on Hospitalization Rates: Insights From Nationwide Readmission Database

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BACKGROUND: Hospitalization rates after transcatheter aortic valve replacement (TAVR) remain high, given the age and comorbidities of patients undergoing TAVR. To better understand the impact of TAVR on hospitalization, we sought to compare hospitalization rates before and after TAVR and to examine if underlying patient comorbidities are associated with a differential effect of TAVR on hospitalizations.

METHODS AND RESULTS: We used the Nationwide Readmissions Database to identify patients who underwent TAVR. As Nationwide Readmissions Database data do not cross over calendar years, we limited our index admission to hospitalizations during April to September of each calendar year to allow 90 days of observation before and after TAVRs. We calculated the daily risk of all-cause hospitalization and used a mixed-effects logistic regression model to explore interactions between patient characteristics, TAVR, and hospitalization risk. Among 39 249 patients who underwent TAVR in 2014 to 2017 (median age, 82 years [interquartile range, 76–87 years]; 45.7% women), 32.0% had at least one hospitalization in the 90 days before TAVR compared with 23.2% in the 90 days post-TAVR (relative reduction, 27.5%; *P*<0.001). In the mixed-effects logistic regression model, TAVR was associated with decreased all-cause hospitalization rate after TAVR in all comorbidity subgroups. However, younger patients and those with heart failure and reduced ejection fraction appeared to have more robust reduction in hospitalizations.

CONCLUSIONS: Although patients who are treated with TAVR have high rates of rehospitalization, TAVR is associated with an overall reduction in all-cause hospitalizations regardless of underlying patient comorbidities.

Key Words: comorbidities ■ hospitalizations ■ transcatheter aortic valve replacement

Through increasing resistance to systolic ejection, aortic stenosis results in left ventricular pressure overload that leads to hypertrophy followed by fibrosis, diastolic dysfunction, and eventually heart failure.[1] Consequently, aortic stenosis is associated with frequent hospitalizations and health care costs >$2 billion/year.[2] Given an absence of pharmacological therapies, the definitive treatment for aortic stenosis is valve replacement, which is increasingly performed by transcatheter aortic valve replacement (TAVR) rather than surgery.[3] Early data in patients at extreme surgical risk showed that TAVR was associated with fewer hospitalizations compared with medical therapy.[4] Subsequent analyses have primarily focused on readmissions after TAVR, which are common (17% at 1 month and 42% at 6 months)[5] and often driven by the age and comorbidities of patients undergoing TAVR.[6]

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For Sources of Funding and Disclosures, see page 6.

CLINICAL PERSPECTIVE

What Is New?

- When considering the hospitalization burden both before and after the procedure, transcatheter aortic valve replacement was associated with a significant reduction in risk of hospitalization.
- This overall reduction was primarily caused by a marked reduction in hospitalizations attributable to cardiovascular causes counterbalanced by a small increase in noncardiovascular hospitalizations after transcatheter aortic valve replacement.
- Younger patients and those with heart failure and reduced ejection fraction appeared to have a differential increased benefit of transcatheter aortic valve replacement in reducing hospitalization risk.

What Are the Clinical Implications?

- Future studies should examine how technological advances with transcatheter aortic valve replacement, processes of care, and variation in patient sociodemographic (eg, race/ethnicity and insurance status) impact the risk of noncardiovascular hospitalizations after the procedure.
- Furthermore, it will be important to explore this association in low-risk patients, who are generally younger and healthier and have an overall lower hospitalization burden compared with the patients in our study.

Nonstandard Abbreviations and Acronyms

HFrEF	heart failure with reduced ejection fraction
NRD	National Readmissions Database
TAVR	transcatheter aortic valve replacement

Although most studies have to date focused on the rates and causes of rehospitalizations after TAVR, less is known about the change in hospitalization rates before and after TAVR.[7] Given the burden of hospitalization before TAVR attributable to aortic stenosis and resultant heart failure, it is crucial to examine the rates of hospitalization pre-TAVR and post-TAVR to put these rehospitalization rates in proper context. Furthermore, it is not known whether particular patient conditions modify the benefit of TAVR on hospitalization (eg, do patients with left ventricular systolic dysfunction have a greater decrease in risk of hospitalization after TAVR). We therefore used the National Readmissions Database (NRD) to provide additional insight into this question as to potential heterogeneity of treatment benefit of TAVR on hospitalization rates (or risks).

METHODS

Study Cohort

The NRD is a part of the Healthcare Cost and Utilization Project of the Agency for Healthcare Research and Quality and includes deidentified data on discharges from all payers from 22 states (up to 28 states in NRD 2017), accounting for 60% of the US population and 58% of US hospitalizations. A unique patient identifier variable allows patients to be tracked for readmission during the same calendar year but not across years (ie, patients receive a new unique identifier if readmitted in a new calendar year). The NRD data elements include hospital characteristics, patient demographics, chronic comorbidities, procedures, primary and secondary discharge diagnoses, length of stay, and payment source.[8] As the NRD is a publicly available database with deidentified patient data, this study was deemed exempt by the Saint Luke's Hospital Institutional Review Board. The data used for this analysis are available from the corresponding author on reasonable request.

We used the *International Classification of Diseases, Ninth Revision, Procedure Coding System* (*ICD-9-PCS*)/*International Classification of Diseases, Tenth Revision, Procedure Coding System (ICD-10-PCS*), to identify hospitalizations that included TAVR between 2014 and 2017 (Table S1). Other hospitalizations were categorized as cardiovascular (primary *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*), code 390–459 or *International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM)*, code I00–I99) or noncardiovascular.[7,9] As we were unable to track patients across years (NRD resets patient identifiers each calendar year), we included only patients who underwent TAVR between April 1 and September 30, to allow 90 days of assessment before and after the TAVR procedure.[10] To assess the time period beyond 90 days, we performed a sensitivity analysis including patients who underwent TAVR between April 1 and June 30 and compared the daily hospitalization risk in the 90 days before TAVR versus 180 days after. We excluded patients aged <18 years and those who died during the index admission or had unknown discharge disposition. Patient comorbidities were defined either by using NRD chronic comorbidity variable elements or by applying equivalent *ICD-9-CM/ICD-10-CM* codes.

Statistical Analysis

Because the goal of our study was to examine the relationship between TAVR and hospitalization rates before and after the procedure, all analyses excluded the TAVR hospitalization, itself. We first calculated the percentage of patients who were in the hospital each day during the 90 days before and after TAVR (TAVR hospitalization excluded) and plotted this daily hospitalization rate over time. We compared the percentage of patients who had at least one hospitalization before versus after TAVR using χ^2 tests and the mean number of days in the hospital before versus after TAVR using paired *t*-tests. These comparisons were performed in the overall cohort and within the following patient subgroups: age (<80 versus ≥80 years), sex, heart failure with reduced ejection fraction (HFrEF), chronic pulmonary disease, chronic kidney disease, atrial fibrillation, diabetes, and pulmonary hypertension. We also compared the percentage of patients with at least one cardiovascular hospitalization in the 90 days before versus 90 days after TAVR.

We then used a mixed-effects logistic regression model to examine the association between TAVR and risk of hospitalization, with TAVR included as a time-dependent variable and a random effect for patient. TAVR was modeled as a cubic spline with knots at −30, −10, 10, and 30 days to account for the nonlinear association between days from the procedure and hospitalization risk. We included fixed effects for patient characteristics (age [<80 versus ≥80 years], sex, HFrEF, chronic lung disease, chronic kidney disease, atrial fibrillation, diabetes, hypertension, and pulmonary hypertension) and TAVR-by-patient characteristic interactions to examine whether particular patient characteristics were associated with differential effects of TAVR on hospitalization risk. Stratified analyses were conducted for all interactions significant at *P*<0.1. SAS 9.4 (SAS Institute Inc, Cary, NC) was used for analyses.

RESULTS

Study Population

Among 78 023 patients who underwent TAVR between 2014 and 2017, we excluded 37 919 with an index TAVR admission in January to March or October to December, 830 who died during the TAVR hospitalization or had unknown discharge disposition, and 25 in whom the TAVR hospitalization was not an index procedure. As such, our analytic cohort included 39 249 patients. Median age was 82 (interquartile range, 76–87) years, 45.7% were women, median length of stay was 3 days (interquartile range, 2–6 days), and 91.2% had Medicare as a primary payer source (Table). Both cardiac and noncardiac comorbidities were common. Most patients in our cohort were treated at hospitals that were metropolitan teaching (89.0%), private nonprofit (84.0%), and large (325+) bed size (76.7%).

Table. Characteristics of Patients at the Time of TAVR

Characteristic	Value (N=39 249)
Age, y	82 (76–87)
Women	17 926 (45.7)
Heart failure with reduced ejection fraction	9199 (23.4)
Coronary artery disease	25 923 (66.0)
Atrial fibrillation	15 246 (38.8)
Diabetes	14 326 (36.5)
Chronic kidney disease	13 243 (33.7)
Chronic lung disease	11 728 (29.9)
Peripheral vascular disease	9659 (24.6)
Pulmonary hypertension	7410 (18.8)
Tricuspid regurgitation	1609 (4.1)
Primary payer	
Medicare	35 766 (91.2)
Medicaid	427 (1.1)
Private insurance	2288 (5.8)
Self-pay	427 (1.1)
Other	341 (0.8)
Length of stay, d	3 (2–6)
Discharge disposition	
Home (self-care)	21 530 (54.9)
Home health care services	11 314 (28.8)
Skilled nursing facility	6240 (15.9)
Short-term hospital	165 (0.4)

Data are presented as median (interquartile range) or number (percentage). TAVR indicates transcatheter aortic valve replacement.

Hospitalization Rates

Figure 1 shows the daily hospitalization rate in the 90 days before and after TAVR. Hospitalization rates gradually increased up to the time of TAVR. After TAVR, the frequency of rehospitalization peaked on day ~13 and decreased gradually thereafter. Over the 90 days before TAVR, 32.0% of patients had at least one hospitalization compared with 23.2% in the 90 days after TAVR (relative reduction, 27.5%; *P*<0.001). The cardiovascular 90-day hospitalization rate decreased from 24.8% to 10.6% (relative reduction, 57.2%; *P*<0.001), whereas the noncardiovascular hospitalization rate increased from 10.7% to 15.3% (relative increase, 30.0%; *P*<0.001). In the sensitivity analysis limited to TAVR index admissions from April 1 to June 30 (19 073 patients), the all-cause hospitalization daily rate continued to decrease between 90 and 180 days after TAVR (Figure 2).

Probability of Hospitalization by Patient Factors

In the mixed-effects logistic regression model, TAVR was associated with decreased all-cause rehospitalization regardless of underlying comorbidities (Figure 3). All interactions between patient factors,

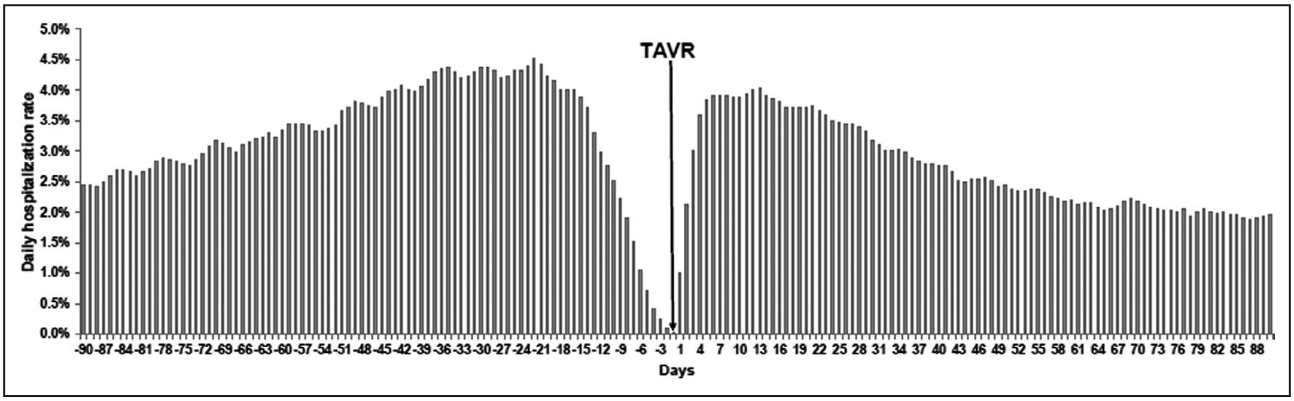

Figure 1. Daily hospitalization rate for 3 months before and after transcatheter aortic valve replacement (TAVR) index hospitalization.

TAVR, and hospitalization risk were significant at *P*<0.001, suggesting this analysis was overpowered. Younger patients (aged <80 years) had an apparent larger decrease in hospitalization risk after TAVR compared with older patients (aged ≥80 years; Figure 3A and Table S2). Patients with HFrEF had a sharp increase in hospitalization risk leading up to TAVR and a sharp decline after TAVR (Figure 3C and Table S2), with significant reduction in the mean total number of days in the hospital in the 90 days before versus after TAVR (4.5±8.7 versus 3.3±8.5 days; *P*<0.001; Table S2). Patients without HFrEF also had a lower hospitalization risk after TAVR, but this decrease after TAVR was less pronounced (mean number of days in the hospital 90 days before versus after TAVR, 2.4±6.1 versus 2.2 ± 6.4; *P*<0.001; Table S2).

Among the other patient subgroups, women and patients with chronic lung disease, chronic kidney disease, atrial fibrillation, diabetes, and pulmonary hypertension each had higher hospitalization risk both before and after TAVR compared with men and with patients without that particular comorbidity; however, the patterns of reduction were similar among those patient subgroups (Figure 3 and Table S2). The pattern of daily all-cause hospitalization risk was similar across the study years, with overall declines in hospitalization risk over time even with adjustment for patient factors (Figure S1).

DISCUSSION

In this analysis of a nationwide real-world sample of patients who underwent TAVR between 2014 and 2017, TAVR was associated with a significant reduction in all-cause hospitalization risk and days in the hospital over a 90-day period before and after valve replacement.

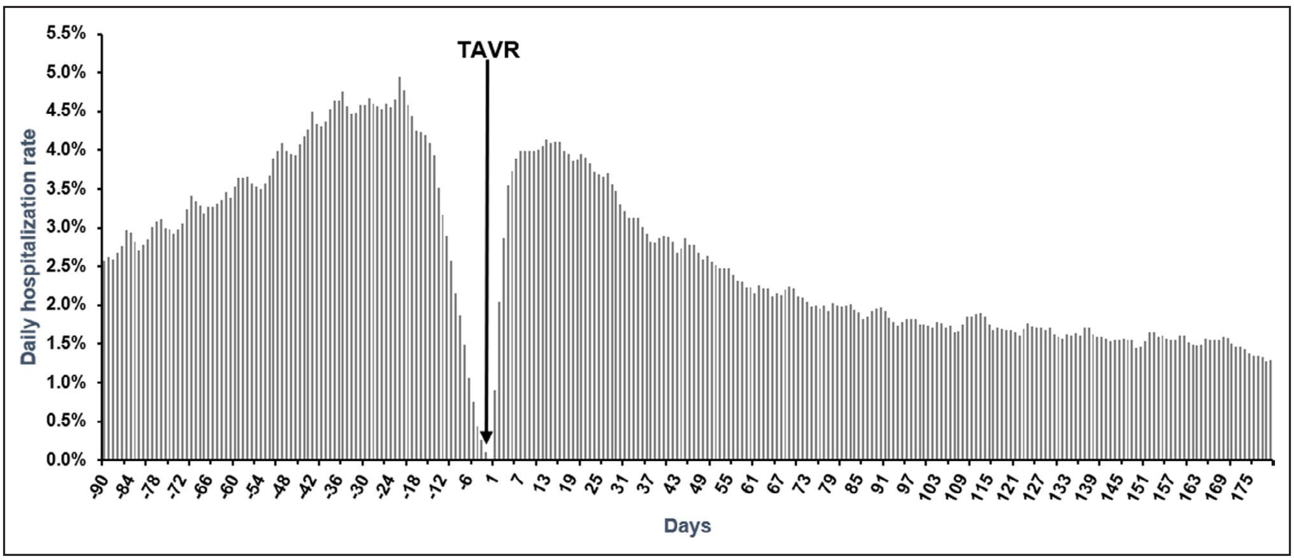

Figure 2. Daily hospitalization rate for 3 months before and 6 months after transcatheter aortic valve replacement (TAVR) index hospitalization.

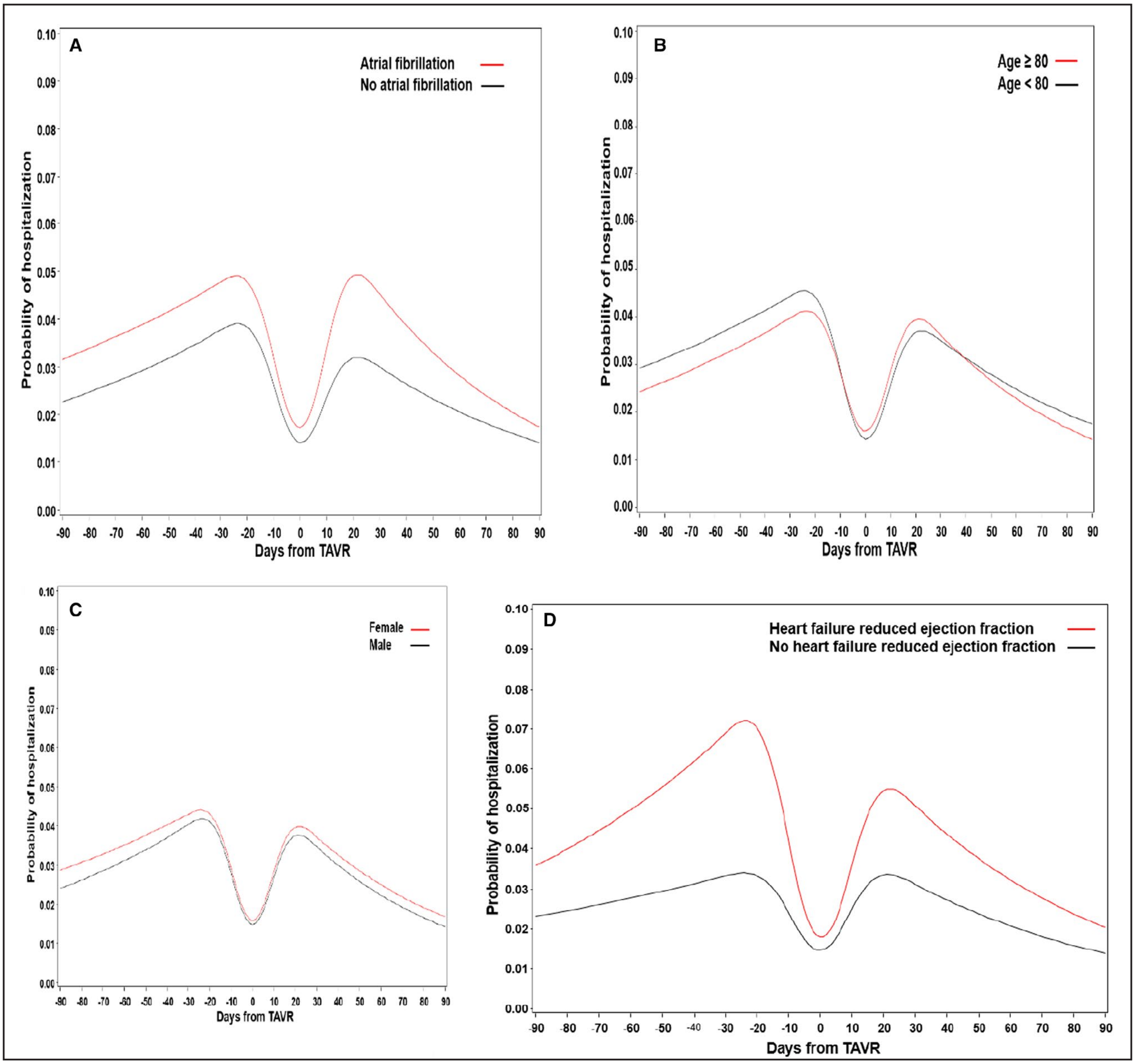

Figure 3. Daily probability of hospitalization before and after transcatheter aortic valve replacement (TAVR), stratified by patient factors.

A, Patients with vs without atrial fibrillation. **B**, Patients aged <80 vs ≥80 years. **C**, Male vs female patients. **D**, Patients with vs without heart failure with reduced ejection fraction. **E**, Patients with vs without chronic lung disease. **F**, Patients with vs without chronic kidney disease. **G**, Patients with vs without diabetes. **H**, Patients with vs without pulmonary hypertension.

This reduction was driven by a marked reduction in cardiovascular hospitalizations, counterbalanced by a slight increase in the noncardiovascular hospitalizations. This reduction in hospitalizations was maintained up to 6 months after TAVR and was relatively consistent across patient subgroups. These findings are reassuring that, despite relatively high readmission rates post-TAVR, these rates represent an improvement in the risk of hospitalization.

Two patterns of hospitalization among patient subgroups require further discussion. First, we note that patients with HFrEF appear to have a more robust reduction in hospitalization risk after TAVR compared with those without HFrEF, potentially indicating greater benefit from TAVR in this subgroup. Second, there appeared to be a greater benefit of TAVR on reducing hospitalizations in younger patients. This is likely attributable to a higher risk for noncardiac hospitalizations in older patients and, perhaps, higher risk for TAVR-related complications (eg, stroke and bleeding). It is important to emphasize, however, that we did not identify a subgroup of patients whose

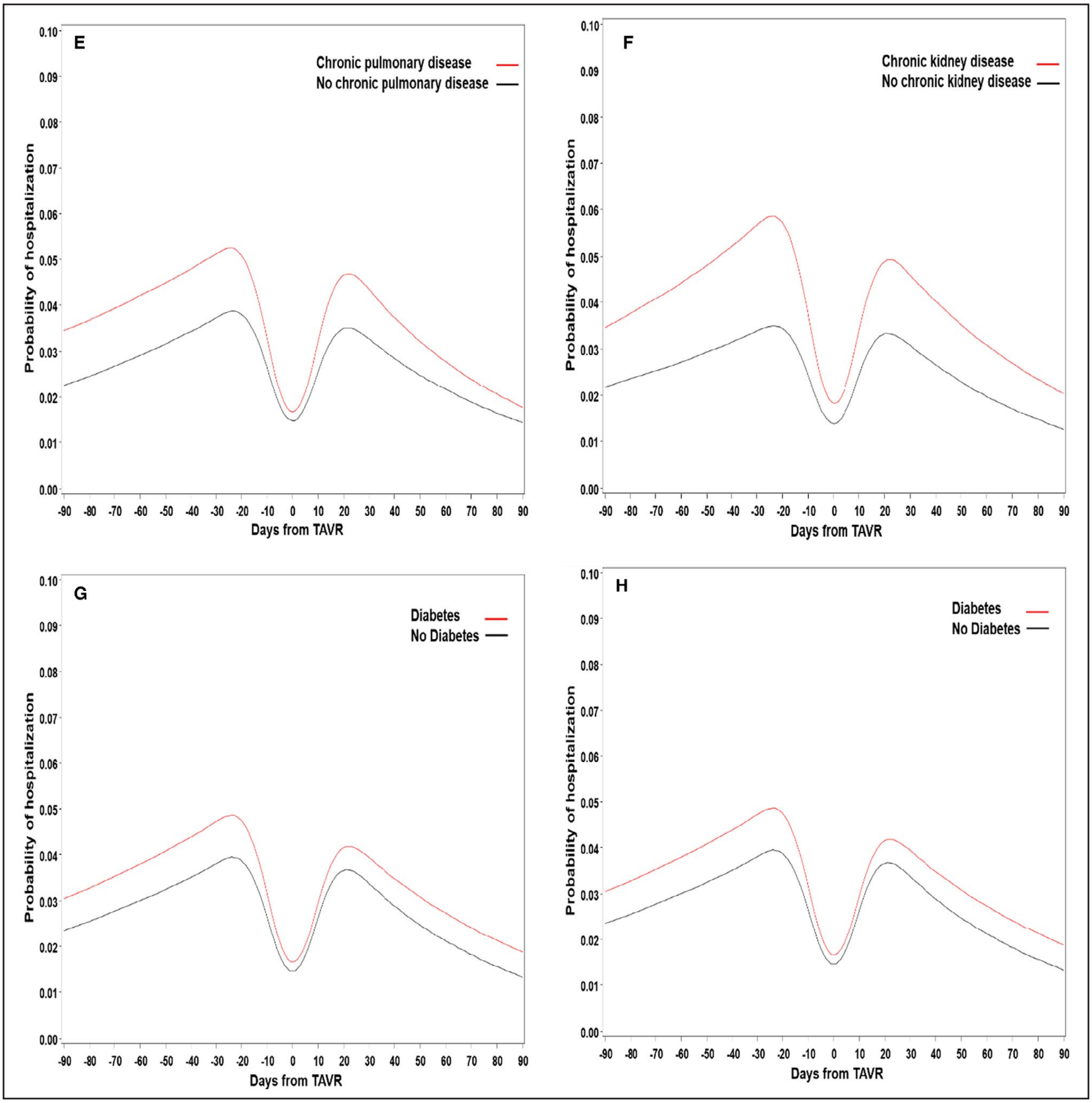

Figure 3. Continued

noncardiac hospitalization risk was so high that there was not evident benefit of TAVR in reducing all-cause hospitalizations.

Prior Studies

Although most of the available data about TAVR and hospitalizations are mainly focused on the post-TAVR readmission rates, 2 studies have examined change in hospitalization risk after TAVR. Our results are similar to a study using administrative data from Ontario, Canada, from 2013 to 2017, where they found that TAVR was associated with an overall reduction in all-cause hospitalizations, most prominently between 31 and 90 days after the procedure.[11] In contrast to our findings, however, a study from the Society of Thoracic Surgeons/American College of Cardiology Transcatheter Valve Therapy Registry using data from the Centers for Medicare & Medicaid Services from 2011 to 2014 found similar all-cause hospitalization rates 1 year before versus 1 year after TAVR, as the reduction in heart failure–related hospitalizations was counterbalanced by an increase in non–heart failure–related hospitalizations after TAVR.[7] Our finding of a decrease in all-cause hospitalizations after TAVR is likely attributable to inclusion of more recent data, with advancements in TAVR techniques and more transfemoral access, leading to fewer complications. In addition, the population of patients eligible for TAVR has become younger and healthier over time, leading to lower rates of noncardiac hospitalizations. Our analysis extends these prior studies by specifically exploring different comorbidities and how they may differentially impact the risk of hospitalization with TAVR.

Limitations

Our findings should be interpreted in light of several important limitations. First, NRD is an administrative database, which carries an inherent risk of miscoding or undercoding for underlying comorbidities. Second, we cannot account for out-of-hospital mortality after TAVR, which could lead to a false reduction in hospitalizations (ie, patients were unable to be rehospitalized because they were dead). However, given the 30-day post-TAVR mortality rate during the time of our study was ~3%,[12] it is unlikely that this meaningfully impacted our findings. Finally, as NRD data do not cross over calendar years, our observation window was limited to 90 days before and after TAVR.

CONCLUSIONS

In a large nationwide sample of patients who underwent TAVR between 2014 and 2017, we found that patients were at high risk for readmission in the 90 days after TAVR; nonetheless, this risk was significantly lower than before TAVR. This lower risk of hospitalization was driven by a marked decrease in risk of cardiovascular hospitalization after TAVR, counterbalanced by a small increase in noncardiovascular hospitalization risk. Although TAVR was associated with a significant reduction in risk for hospitalization in all comorbidity subgroups, there appeared to be a differential increased benefit of TAVR in reducing hospitalization risk in both younger patients and those with HFrEF. Our findings better define the risk of hospitalization before and after TAVR, both overall and in particular subgroups, and are reassuring that the high readmission rates after TAVR represent an improvement from those before TAVR.

ARTICLE INFORMATION

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Disclosures

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Supplementary Material

Tables S1-S2
Figure S1

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SUPPLEMENTAL MATERIAL

Table S1. TAVR International Classification of Diseases, Ninth and Tenth Revision, Procedure Classification System.

	ICD-9 CM or PCS code	ICD-10 CM or PCS codes
TAVR	3505 3506	02RF37H 02RF37Z 02RF38H 02RF38Z 02RF3JH 02RF3JZ 02RF3KH 02RF3KZ 02RF47Z 02RF48Z 02RF4JZ 02RF4KZ
Heart failure reduced ejection fraction	42820 42821 42822 42823, 42840 42841 42842 42843	I502, I5020, I5021, I5022, I5023, I504, I5040, I5041, I5042, I5043
Atrial fibrillation	42731	I480 I481 I482 I4891
Chronic kidney disease	585 5851 5852 5853 5854 5855 5856 5859 7925 V420 V451 V4511 V4512 V560 V561 V562 V5631 V5632 V568	N181 N182 N183 N184 N185 N186 N189 R880 Z4901Z4902 Z4931Z4932 Z9115 Z940 Z992
Pulmonary hypertension	4160	I270 I272 I2720 I2721 I2722 I2723 I2724 I2729
Diabetes Mellitus	AHRQ comorbidity measure for ICD-9/10-CM codes: diabetes, uncomplicated and complicated	
Hypertension	AHRQ comorbidity measure for ICD-9/10-CM codes: hypertension (combine uncomplicated and complicated)	

Chronic lung disease	AHRQ comorbidity measure for ICD-9/10-CM codes: chronic pulmonary disease

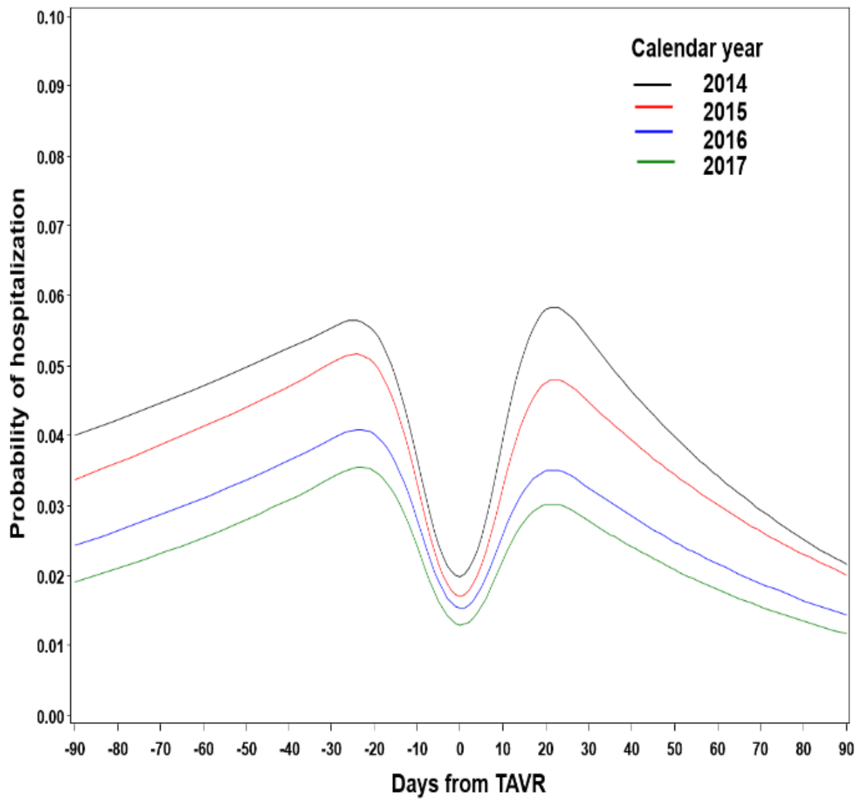
Table S2. All-cause hospitalization rate and mean days in the hospital in the 90 days before versus after TAVR among subgroups.

	n	Hospitalization Rate (%)[1]		Mean Days in Hospital*	
		Pre-TAVR	Post-TAVR	Pre-TAVR	Post-TAVR
Age ≥80 years	24,420	31.8	23.8	2.8 ± 6.4	2.4 ± 6.7
Age <80 years	14,829	32.3	22.3	3.1 ± 7.6	2.5 ± 7.4
Male	21,323	31.7	22.8	2.8 ± 6.7	2.4 ± 6.8
Female	17,926	32.3	23.7	3.1 ± 7.1	2.6 ± 7.1
Heart failure reduced ejection fraction	9,199	42.6	26.6	4.5 ± 8.7	3.3 ± 8.5
No heart failure reduced ejection fraction	30,050	28.7	22.2	2.4 ± 6.1	2.2 ± 6.4
Chronic lung disease	11,728	36.3	26.1	3.7 ± 7.8	2.9 ± 7.6
No chronic lung disease	27,520	30.2	22.0	2.6 ± 6.4	2.3 ± 6.7
Chronic kidney disease	13,243	38.7	27.5	3.9± 8.1	3.1 ± 8.0
No chronic kidney disease	26,006	28.5	21.0	2.4 ± 6.1	2.1 ± 6.4
Atrial fibrillation	15,246	35.6	26.9	3.4 ± 7.2	3.0 ± 7.6
No atrial fibrillation	24,003	29.7	20.9	2.6 ± 6.6	2.1 ± 6.5
Diabetes mellitus	14,326	35.1	25.0	3.3 ± 7.3	2.8 ± 7.4
No diabetes mellitus	24,922	30.2	22.2	2.7 ± 6.6	2.3 ± 6.7
Pulmonary hypertension	7,410	36.1	26.3	3.8 ± 8.0	3.2 ± 8.2
No pulmonary hypertension	31,839	31.0	22.5	2.7 ± 6.6	2.3 ± 6.6

*All comparisons of pre- versus post-TAVR were significant at $p<0.001$

Figure S1. Daily probability of hospitalization before and after TAVR stratified by year. A. Unadjusted. B. Adjusted for patient factors (age, sex, heart failure reduced ejection fraction, chronic lung disease, chronic kidney disease, atrial fibrillation, diabetes mellitus, hypertension, pulmonary hypertension)

A. Unadjusted



B. Adjusted