Quantifying the Impact of Care Fragmentation on Outcomes After Transcatheter Aortic Valve Implantation

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The Center for Medicare & Medicaid Services has identified readmission as an important quality metric in assessing hospital performance and value of care. The aim of this study was to quantify the impact of "care fragmentation" on transcatheter aortic valve implantation (TAVI) outcomes. Readmission to nonindex hospitals was defined as any hospital other than the hospital where the TAVI was performed. In this multicenter, population-based, nationally representative study, a nationally weighted cohort of US adult patients who underwent TAVI in the National Readmission Database between 01/01/2010 and 9/31/2015 were analyzed. Patient characteristics, trends, and outcomes after 90-day nonindex readmission were evaluated. Thirty-day metric was used as a reference group for comparison. A weighted total of 51,092 patients met inclusion criteria. Overall, the 90-day readmission rate after TAVI was 27.6% (30-day reference group: 17.4%), and 42% of these readmissions were to nonindex hospitals. Noncardiac causes accounted for most nonindex readmissions, but major cardiac procedures were more likely performed at index hospitals during readmission within 90 days. Despite the high co-morbidity burden of patients readmitted to nonindex hospitals, unadjusted and risk-adjusted all-cause mortality, readmission length of stay and total hospital costs following nonindex readmission were lower compared with index readmission at 90 days. In conclusion, in this real world, nationally representative cohort of TAVI patients in the United States, care fragmentation remains prevalent and represent an enduring, residual target for future health policies. Although the impactful readmissions may be directed toward index hospitals, concerted efforts are needed to address mechanisms that increase care fragmentation. **(Am J Cardiol 2020;128:113−119)**

The Centers for Medicare and Medicaid Services (CMS) has identified readmission as an important quality metric in assessing hospital performance and instituted the Hospital Readmission Reduction Program (HRRP) for certain target medical conditions and procedures/surgeries.[1,2] Despite these efforts, unplanned readmissions after index hospitalization have persisted, and are associated with increased healthcare costs and resource utilization.[3−5] However, in the context of transcatheter aortic valve implantation (TAVI), the mechanisms and impact of care fragmentation within the framework of HRRP and other health policies remains unclear. Furthermore, TAVI is currently not targeted under HRRP, but in the future, it may be considered as one of the target conditions given its considerable growth and widespread adoption in the management of patients with severe aortic valve stenosis.[6−8] Thus, as TAVI expands to more sites given the recent changes in the National Coverage Determination guidelines, it will be crucial to quantify care fragmentation for quality control. This study explores trends, causes, and subsequent outcomes after readmission to a facility other than the one where the surgery was performed using a large population-based database.

Methods

This population-based, nationally representative study retrospectively analyzed the National Readmissions Database (NRD). This is a unique and powerful database to allow for a national assessment of hospital inpatient stays and readmissions among patients of all ages and across all payer types inclusive of private and government insurance and the uninsured. While the NRD contains verified patient identifiers to track individuals across hospital admissions within and across a state's hospitals,[9] this database contains completely de-identified data (ie, no social security numbers or patient-specific identifiers) using unique patient keys that are tracked by the state. The NRD is drawn from

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Funding: Cheryl K Zogg, MSPH, MHS, is supported by NIH Medical Scientist Training Program Training grant T32GM007205. She is the PI of an F30 award through the National Institute on Aging F30AG066371 entitled "The ED.TRAUMA Study: Evaluating the Discordance of Trauma Readmission and Unanticipated Mortality in the Assessment of hospital quality."

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See page 118 for disclosure information.

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https://doi.org/10.1016/j.amjcard.2020.05.005

the Agency for Healthcare Research and Quality's (AHRQ) state inpatient databases and contains data from approximately 17 million discharges each year, representing 36 million discharges when weighted to yield national estimates of inpatient stays. This NRD is closely mandated and managed by AHRQ, and is a collaborative ef'fort between state data organizations, hospital associations, private data organizations, and the federal government. National weights are provided by AHRQ to account for available data derived from individual state inpatient claims. Because the NRD is a publicly available de-identified database, this study was exempt from review by our institutional review board.

We selected all US adult patients (age ≥18 years) from the NRD admitted between January 1, 2010 and September 31, 2015 for isolated TAVI. These patients were identified using the International Classification of Disease, Ninth Edition, Clinical Modifications (ICD-9-CM) procedure codes 35.05 and 35.06. The study period was chosen to allow for 90-day follow-up data. We excluded patients who underwent concomitant surgical aortic valve replacement (SAVR), coronary artery bypass surgery or other cardiac surgery during the same index hospital admission. Patients who died during the index hospitalization, and those with missing discharge disposition or readmission were excluded from the analysis. The study CONSORT flow diagram highlights our selection process (Supplement eFigure 1).

We utilized ICD-9-CM diagnosis codes to capture baseline patient characteristics, relevant complications, TAVI access site (ie, endovascular vs transapical), in-hospital procedures (eg, coronary angiography, percutaneous coronary intervention (PCI), and mechanical circulatory support), in-hospital complications (eg, conversion to SAVR, complete heart block, transient ischemic attack/stroke) and major complications (pneumonia, pulmonary embolism, renal failure, cerebrovascular accident, myocardial infarction, cardiac arrest, adult respiratory distress syndrome, sepsis, and septic shock)[10] (Supplement eTable 1). The Charlson co-morbidity index, which was also calculated using ICD-9-CM codes, attaches weights to common comorbid medical conditions to summarize the comorbidity burden for an individual.[11] Age was included as a categorical variable in deciles of age.

The primary outcomes were annual trends and proportion of index and nonindex readmissions at 90 days after TAVI. Nonindex readmission was defined as readmission to any hospital other than the hospital where the TAVI was performed. Secondary outcome variables were in-hospital mortality, major complications, causes of readmissions, readmission length of stay (LOS), total readmission hospital costs, and subsequent readmissions for patients admitted to index versus nonindex hospitals.

Descriptive analyses were performed for 90-day readmission by index and nonindex hospital status. The

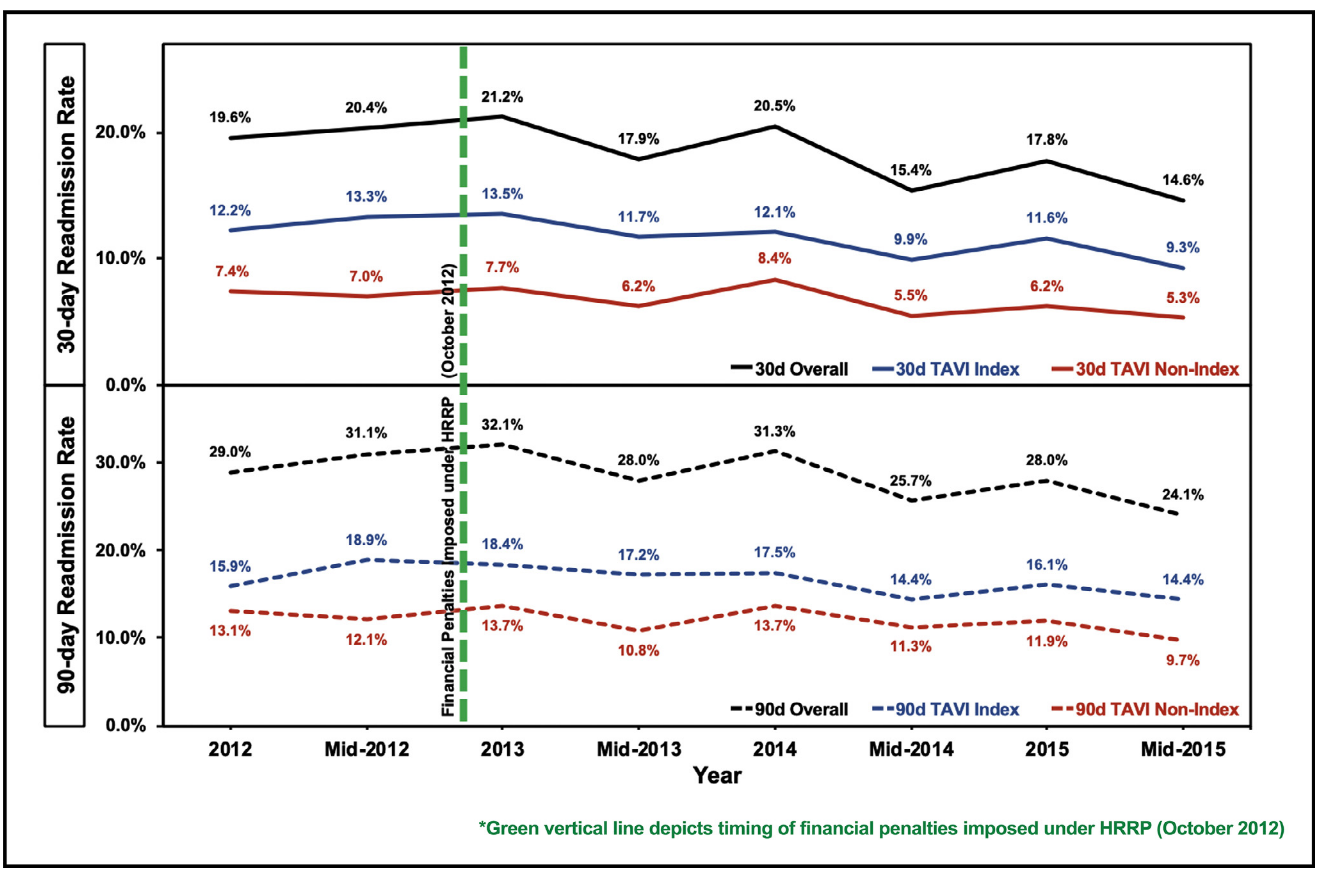

Figure 1. Temporal trends in overall, index, and nonindex 90-day readmission rates after TAVI. Green vertical line depicts timing of financial penalties imposed under HRRP (October 2012). Thirty-day is the reference group.

rationale for using the 90-day period was to reliably capture enough readmission events and allow for robust risk-adjusted analysis. Thirty-day outcome was used as a reference group for comparison. Time to readmission and primary admission length of stay were used to calculate the number of days to readmission.[12] Readmission proportions were calculated only for patients who survived to discharge. For patients who had multiple readmission within 30 and 90 days, only the first readmission was included. Transfer to another hospital was not considered as a readmission. Planned readmissions after TAVI are expected to be extremely rare because unlike PCI, there are no staged procedure involved. Normally distributed continuous variables are expressed as a mean with standard deviation and compared using Student's *t* tests with Levene's test for homogeneity of variance. Kruskal-Wallis (nonparametric) one-way analysis of variance was used to compare non-normally distributed continuous variables. Categorical variables are presented as number and percentages and compared using χ^2 or Fisher's exact tests depending on distribution. Survey data analysis tools were utilized to generate weighted national estimates and variances that accounted for weighting, clustering of outcomes within hospitals, and sampling variation across strata (region and year).

Significant independent predictors of 30- and 90-day nonindex readmission after TAVI were identified based on consensus addition/removal of forward and backward selection using an inclusion/exclusion threshold of 2-sided p value ≤0.05 (rounded down). The resultant models were confirmed not to be significantly different from the complete models (inclusive of all of the terms shown in Supplement eTable 2) based on comparison of the ln(likelihoods) for the full and reduced nested models. These independent predictors were used in our risk-adjusted analysis. Risk-adjusted models were also calculated using inverse-probability of treatment weighting based on calculated propensity scores for a priori defined: age, gender, income, operative emergency, Charlson co-morbidity index, hospital size, hospital teaching status, and patient residential population. Additionally, annual trends in index versus nonindex readmission at 30 and 90 days were also assessed. Causes of readmissions were classified as cardiac (eg, heart failure, arrhythmias, conduction disorders) and noncardiac (eg, respiratory, infectious, bleeding, trauma). Quintile regression was used for LOS and total readmission hospital cost. These costs were obtained from reported readmission total hospital charges and converted to costs using cost: charge ratios and adjusted for inflation to be reported in 2018 US dollars. All analyses were conducted using STATA Version 13.1 (StataCorp LP, College Station, TX) with 2-sided p ≤0.05 as the criterion for significance.

Results

A weighted total of 51,092 TAVI procedures met inclusion criteria. Among the patients who were discharged alive (n = 49,094), the 90-day readmission rate was 27.6% (12,954 patients). In comparison, the 30-day readmission

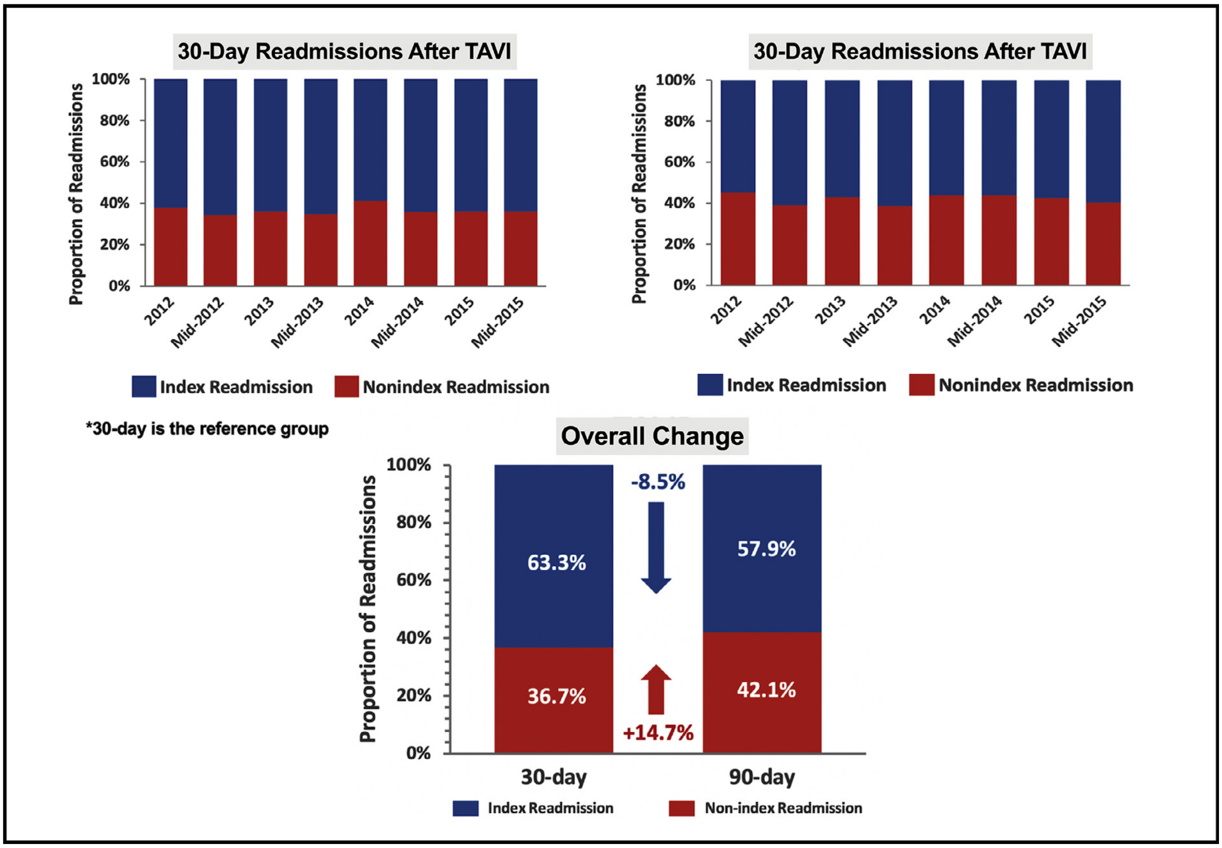

Figure 2. Temporal trends and change in proportion of Index v nonindex readmission after TAVI at 90 days. Thirty-day is the reference group.

rate was 17.4% (7,969 patients). Despite an overall decreasing trend in annual 90-day readmission rates that was more pronounced after the implementation of HRRP policies (p <0.05), the proportion of nonindex readmissions was considerable, and remained relatively unchanged over time (42.1%, a relative increase of +14.7% from that at 30 days; both p >0.05; Figures 1 and 2).

Differences in initial patient and hospital characteristics between nonindex hospital and index hospital readmissions at 90 days are summarized in Supplement eTable 2. In general, patients readmitted to nonindex hospitals were proportionally older in age (age 75 to 84 years: 39.6% vs 37.8%; age ≥85 years: 43.8% vs 44.2%; p = 0.84), and more likely resided in areas that were either suburban (33.1% vs 27.8%; p <0.001) or in the same state as the initial hospital from which they were discharged (97.2% vs 89.1%; p <0.001). Patients readmitted to nonindex hospitals also had a higher comorbidity burden that is, higher prevalence of diabetes mellitus, hypertension, chronic lung disease, and previous stroke.

The majority of the 90-day readmissions at nonindex hospitals were because of noncardiac causes (38.5%) and comprised of mainly infectious (10%) and respiratory etiologies (7%; Supplement eTable 3). However, major cardiac procedures such as cardiac catheterization, angiography, permanent pacemaker placement (PPM), pericardiocentesis were more likely to be performed at index hospitals, even after risk-adjustment (Supplement eTable 4). On multivariable analysis, factors that were more likely to be associated with nonindex readmission at 90 days were higher income, living in rural or suburban areas (smaller counties), being a resident in the same state, elective nature of the index procedure, higher Charlson co-morbidity index and metropolitan teaching status of the hospital. Factors predicting 30-day nonindex readmissions are also summarized in Table 1.

Despite the higher risk profile of patients readmitted to nonindex hospitals, rates of unadjusted all-cause mortality (5.3% vs 5.1%), readmission LOS (50th percentile 4 vs 4 days; 95th percentile 19 vs 16 days) and total hospital costs (50th percentile $10,563 vs $9,310; 95th percentile $55,701 vs $40,709) following readmission at index hospitals were higher compared with that at nonindex hospitals at 90 days (Table 2). Rates of in-hospital outcomes such as complete heart block, PPM, cardiac arrest, and acute kidney injury were also significantly higher at index versus nonindex hospitals. For comparison, 30-day outcomes are highlighted in Supplement eTable 5. These findings persisted even after risk adjusting for differences in the casemix and rurality of readmitting hospitals.

Table 1
Independent predictors of nonindex hospital versus index hospital 30-day and 90-day readmission following TAVR, nationally weighted results

	30-day readmission risk-adjusted OR (95% CI)	90-day readmission risk-adjusted OR (95% CI)
Median income quartile		
Q1 - lowest	1.00 (reference)	1.00 (reference)
Q2	1.34 (0.98−1.82)	1.27 (1.01−1.58)
Q3	1.32 (0.96−1.80)	1.23 (1.00−1.54)
Q4 - highest	1.22 (0.91−1.65)	1.14 (1.00−1.44)
Patient residential population		
Urban, metro area ≥1 million	1.00 (reference)	1.00 (reference)
Suburban, metro area ≥1 million	1.32 (0.95−1.84)	1.50 (1.15−1.95)
250,000-999,999	0.91 (0.64−1.28)	0.95 (0.72−1.24)
<250,000	1.58 (1.02−2.44)	1.69 (1.19−2.41)
Index hospital in residential state		
No	1.00 (reference)	1.00 (reference)
Yes	5.52 (2.92−10.41)	4.83 (3.13−7.46)
Operative urgency		
Emergent/urgent	1.00 (reference)	1.00 (reference)
Elective	1.10 (1.00−1.35)	1.20 (1.03−1.40)
Charlson co-morbidity index		
0 - lowest	1.00 (reference)	1.00 (reference)
1	1.16 (0.82−1.63)	1.07 (0.82−1.40)
2	1.09 (0.78−1.51)	1.06 (0.83−1.35)
3	0.93 (0.66−1.32)	1.00 (0.76−1.29)
4	1.18 (0.82−1.68)	1.18 (0.88−1.59)
≥5 - highest	1.40 (1.00−1.99)	1.39 (1.05−1.84)
Specific co-morbidities		
Hypertension	1.17 (0.93−1.48)	1.24 (1.05−1.46)
Heart failure	0.64 (0.39−1.06)	0.62 (0.39−0.98)
Prior TIA/stroke	1.24 (0.92−1.66)	1.23 (1.00−1.53)
Hospital teaching status		
Metropolitan non-teaching	1.00 (reference)	1.00 (reference)
Metropolitan teaching	1.20 (0.87−1.65)	1.12 (0.87−1.44)
Non-metropolitan hospital	0.34 (0.23−0.11)	0.27 (0.21−0.35)

Significant independent predictors were identified based on consensus addition/removal of forward and backward selection using an inclusion/exclusion threshold of 2-sided p value ≤0.05 (rounded down). The resultant models were confirmed not to be significantly different from the complete models (inclusive of all of the terms shown in Table e1) based on comparison of the ln(likelihoods) for the full and reduced nested models.

Discussion

This large, nationally representative, multicenter analysis had several important findings: First, care fragmentation was prevalent after TAVI as nonindex readmissions accounted for a considerable proportion of short-term patient readmissions. Furthermore, despite recent improvements in annual readmissions after TAVI, the residual nonindex readmissions remained relatively unchanged over time. Second, the major causes of readmission were primarily noncardiac related both at 90 days after TAVI. In contrast, readmissions appeared to be appropriately triaged to index versus nonindex hospital facilities such that patients requiring major cardiovascular interventions more likely returned to the original TAVI implant hospital. Finally, this study demonstrated that despite the higher risk profile of patients readmitted to nonindex hospitals, clinical outcomes, readmission LOS, and total hospital costs were consistently worse for readmissions to index versus nonindex hospitalizations. These results indicate that while the impactful readmissions may be directed toward index hospitals, care fragmentation after TAVI is consistently evident.

Emerging evidence suggests that fragmented care is associated with worse quality, higher costs and deleterious outcomes of patients.[13−15] However, much of the existing data have primarily focused on medical conditions[16] and have not been explored until now in the context of TAVI.

Table 2
Outcome differences comparing nonindex hospital versus index hospital 90-day readmission following TAVR, nationally weighted results

Outcome	Nonindex readmission (n = 5,455)	Index readmission (n = 7,499)	Unadjusted OR (95% CI)	Risk-adjusted OR† (95% CI)	Risk-adjusted OR‡ (95% CI)
Mortality	278 (5.1%)	397 (5.3%)	0.96 (0.72−1.29)	0.97 (0.73−1.31)	0.95 (0.71−1.30)
Major complication(s)	2,318 (42.5%)	3,075 (41.0%)	1.06 (0.93−1.21)	1.07 (0.94−1.21)	1.04 (0.91−1.19)
In-hospital outcome(s)	1,735 (31.8%)	2,835 (37.8%)	0.77 (0.65−0.90)	0.76 (0.65−0.90)	0.76 (0.64−0.89)
Surgical AVR	11 (0.2%)	30 (0.4%)	0.40 (0.11−1.42)	0.36 (0.10−1.29)	0.33 (0.09−1.19)
Complete heart block	104 (1.9%)	225 (3.0%)	0.63 (0.40−0.98)	0.62 (0.40−0.98)	0.60 (0.38−0.94)
PPM placement	93 (1.7%)	262 (3.5%)	0.47 (0.31−0.74)	0.47 (0.30−0.74)	0.45 (0.29−0.71)
TIA/Stroke	393 (7.2%)	570 (7.6%)	0.94 (0.70−1.23)	0.94 (0.70−1.25)	0.92 (0.68−1.24)
AMI	169 (3.1%)	232 (3.1%)	0.99 (0.66−1.46)	1.00 (0.67−1.49)	1.01 (0.67−1.53)
Cardiogenic shock	5 (0.1%)	0 (0.0%)	5.14 (0.31−85.8)	4.42 (0.27−72.5)	4.19 (0.26−67.7)
Cardiac arrest	38 (0.7%)	127 (1.7%)	0.42 (0.22−0.78)	0.40 (0.21−0.77)	0.37 (0.19−0.73)
Acute kidney injury	1,151 (21.1%)	1,867 (24.9%)	0.81 (0.68−0.96)	0.81 (0.68−0.96)	0.79 (0.66−0.95)
Major bleeding	60 (1.1%)	37 (0.5%)	2.10 (1.08−4.08)	2.18 (1.11−4.31)	2.11 (1.05−4.23)
Vascular complications	38 (0.7%)	37 (0.5%)	1.45 (0.51−4.15)	1.37 (0.48−3.92)	1.71 (0.63−4.61)
Further readmissions required	2,547 (46.7%)	3,427 (45.7%)	1.04 (0.90−1.20)	1.04 (0.90−1.20)	1.01 (0.87−1.17)
Readmission LOS					
50th percentile*	4 days	4 days	0 days (−0.2 to +0.2)	0 days (−0.4 to +0.4)	0 days (−0.3 to +0.3)
75th percentile*	7 days	8 days	0 days (−0.9 to +0.9)	0 days (−1.0 to +1.0)	0 days (−1.0 to +1.0)
95th percentile*	16 days	19 days	+1 day (−1.3 to +3.3)	+2 days (−0.4 to +4.5)	+1 day (−1.6 to +3.6)
LOS ≥5 days	2,378 (43.6%)	3,720 (49.6%)	0.79 (0.69−0.91)	0.79 (0.69−0.91)	0.77 (0.67−0.89)

AVR = aortic valve replacement.

Major complications were defined to include: pneumonia, pulmonary embolism, renal failure, cardiovascular accident, myocardial infarction, cardiac arrest, acute respiratory distress syndrome, sepsis, and severe sepsis.

* Results of quantile regression showing the differences in LOS at the indicated percentile

† Risk-adjusted models were calculated using inverse-probability of treatment weighting based on calculated propensity scores for a priori defined: age, gender, income, operative emergency, CCI, hospital size, hospital teaching status, and patient residential population

‡ Risk-adjusted models were calculated using based on the independent predictors outlined in Table 1.

This study further adds to previous literature and found that the proportion of nonindex readmissions (a metric of care fragmentation) in the short term was still high. What was even more concerning was the fact these proportions remained relatively unchanged at both 30 and 90 days despite existing efforts.

This analysis may also help elucidate the mechanisms that contribute to care fragmentation after TAVI. First of all, it was reassuring that outcomes after nonindex readmission were relatively better than outcomes after index readmission, suggesting adverse selection and shunting of high-risk patients away from index facilities was less likely. However, a certain degree of diversion to observation units, or nonadmission may be occurring or cannot be excluded.[17] Second, the nonindex readmission rate was comparable in patients who did or did not experience a TAVI-related complication. When we closely examined the causes of 30-day readmissions after TAVI, the most common causes at both index and nonindex hospitals were primarily noncardiac in nature (mainly respiratory, infectious and bleeding), as previously highlighted.[3−5,18] Intriguingly, it also appeared that nonindex hospitals treated minor issues while major ones (eg, pericardiocentesis, coronary angiography, permanent pacemaker implantation) were appropriately triaged to index hospitals. This could explain the lower hospital costs associated with nonindex readmissions, even after risk adjustment.

These findings have important long-term implications and emphasize the importance of optimizing and improving transitions of care from inpatient to outpatient settings while developing mechanisms to track patient readmissions, even if done at outside hospitals. Future efforts to minimize readmissions can include creating of home hospital systems for managing minor cardiac issues (eg, atrial fibrillation), development of web- or application-based postoperative management systems that capture/predict early signs of readmission, and optimization of team-based approaches to involve primary care physicians in addition to cardiologists since TAVI patients tend to have multiple medical problems across different organ systems. Along those lines, collaborative models of care between index and nonindex facilities are also becoming increasingly important in an era of Centers of Excellence for TAVI. Spoke-and-wheel referral systems in which high-volume facilities and operators implant TAVIs and care for patients together with referring hospitals would be another option. And finally, long-term care after index TAVI implantation may be best provided with longitudinal referring physicians. Nonetheless, further study is needed to identify the best mechanisms to decrease the extent of care fragmentation on TAVI outcomes.

There are several limitations to this analysis. First, NRD is an administrative database and information on valve type and size, echocardiographic variables, individual patient risk scores, medication use, type of anesthesia and postprocedural paravalvular leaks were not available. Information on STS PROM scores was also not available. Additionally, the category for endovascular TAVI is broad, and it was difficult to delineate each subtype of TAVI. Although our study examined patterns of index versus nonindex readmission, our data could not inform us as to whether there was an affiliation between any of the index and nonindex hospitals for example, large hospital systems with many affiliated satellite hospitals that manage care together. The data could also not inform us as to the number of patients who were transferred back to the index hospital after readmission to a nonindex hospital. Given the nature of the database, no information was available on planned readmission and/or which procedures were under the enhanced recovery after surgery pathway. Hospital volume was not available in the recent NRD version and hence the impact of hospital volume in relation to index versus nonindex readmissions could not be elucidated. Finally, we could evaluate planned readmissions or could not examine long-term outcomes in readmitted patients in index versus nonindex hospital beyond 90 days, which remains an important question that warrants additional study.

In conclusion, in this real world, all payer, nationally representative cohort of TAVI patients in the United States, care fragmentation remains prevalent and represent an enduring, residual target for future health policies. Although the impactful readmissions are directed toward index hospitals, concerted efforts are needed to address mechanisms that increase care fragmentation.

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Disclosures

Author T.K. is a speaker for Edwards Life Sciences, Medtronic, Abbott and Baylis Medical and is a consultant for 4C Medical. Author D.B discloses the following relationships - Advisory Board: Cardax, Cereno Scientific, Elsevier Practice Update Cardiology, Medscape Cardiology, PhaseBio, Regado Biosciences; Board of Directors: Boston VA Research Institute, Society of Cardiovascular Patient Care, TobeSoft; Chair: American Heart Association Quality Oversight Committee; Data Monitoring Committees: Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute, for the PORTICO trial, funded by St. Jude Medical, now Abbott), Cleveland Clinic (including for the ExCEED trial, funded by Edwards), Duke Clinical Research Institute, Mayo Clinic, Mount Sinai School of Medicine (for the ENVISAGE trial, funded by Daiichi Sankyo), Population Health Research Institute; Honoraria: American College of Cardiology (Senior Associate Editor, Clinical Trials and News, ACC.org; Vice-Chair, ACC Accreditation Committee), Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute; RE-DUAL PCI clinical trial steering committee funded by Boehringer Ingelheim; AEGIS-II executive committee funded by CSL Behring), Belvoir Publications (Editor in Chief, Harvard Heart Letter), Duke Clinical Research Institute (clinical trial steering committees, including for the PRONOUNCE trial, funded by Ferring Pharmaceuticals), HMP Global (Editor in Chief, Journal of Invasive Cardiology), Journal of the American College of Cardiology (Guest Editor; Associate Editor), Medtelligence/ReachMD (CME steering committees), Population Health Research Institute (for the COMPASS operations committee, publications committee, steering committee, and USA national co-leader, funded by Bayer), Slack Publications (Chief Medical Editor, Cardiology Today's Intervention), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees); Other: Clinical Cardiology (Deputy Editor), NCDR-ACTION Registry Steering Committee (Chair), VA CART Research and Publications Committee (Chair); Research Funding: Abbott, Afimmune, Amarin, Amgen, AstraZeneca, Bayer, Boehringer Ingelheim, Bristol-Myers Squibb, Chiesi, CSL Behring, Eisai, Ethicon, Ferring Pharmaceuticals, Forest Laboratories, Idorsia, Ironwood, Ischemix, Lilly, Medtronic, PhaseBio, Pfizer, Regeneron, Roche, Sanofi Aventis, Synaptic, The Medicines Company; Royalties: Elsevier (Editor, Cardiovascular Intervention: A Companion to Braunwald's Heart Disease); Site Co-Investigator: Biotronik, Boston Scientific, St. Jude Medical (now Abbott), Svelte; Trustee: American College of Cardiology; Unfunded Research: FlowCo, Fractyl, Merck, Novo Nordisk, PLx Pharma, Takeda. There are no other potential conflicts that exist.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2020.05.005.

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