

# Short Length of Stay After Elective Transfemoral Transcatheter Aortic Valve Replacement is Not Associated With Increased Early or Late Readmission Risk

Maneesh Sud, MD; Feng Qui, MSc; Peter C. Austin, PhD; Dennis T. Ko, MD, MSc; David Wood, MD; Andrew Czarnecki, MD; Vaidehi Patel; Douglas S. Lee, MD, PhD; Harindra C. Wijeyesundera, MD, PhD

**Background**—Elderly patients undergoing transcatheter aortic valve replacement (TAVR) are at risk of hospital readmission postprocedure. It is not known whether the index hospital length of stay and, specifically, early discharge post-TAVR is associated with an increased risk of readmission. We hypothesized a nonlinear relationship whereby both short and long lengths of stay were associated with increased readmission risk.

**Methods and Results**—We performed a retrospective multicenter cohort analysis of patients undergoing elective transfemoral TAVR and surviving to discharge between January 2007 and March 2014. The exposure variable was hospital length of stay measured from the procedure date to the date of discharge and modeled as a continuous variable in a multivariable cause-specific Cox regression. Main outcome measures were 30-day and 1-year all-cause readmissions. The study population consisted of 709 patients with a median length of stay of 6 days (interquartile range, 4–8). At 30-days and 1-year, 13.5% and 44.0% of patients were readmitted, respectively. Although post-TAVR length of stay was not associated with 30-day all-cause readmissions ( $P=0.925$ ), there existed a significant association with 1-year readmission ( $P=0.010$ ) after adjustment for baseline clinical variables. The association between post-TAVR length of stay and 1-year readmission was linear ( $P=0.549$  for nonlinearity) with no evidence supporting an increased readmission risk for shorter length of stays.

**Conclusions**—Among elderly survivors of elective transfemoral TAVR, a short postprocedural length of stay was not associated with an increased risk readmission within 30 days or 1 year. However, the risk of 1-year readmission increased with longer post-TAVR lengths of stay. (*J Am Heart Assoc.* 2017;6:e005460. DOI: 10.1161/JAHA.116.005460.)

**Key Words:** hospitalization • length of stay • readmission • transcatheter aortic valve implantation

Readmission to hospital within 30 days after discharge is a proposed marker of hospital quality of care.<sup>1</sup> Early readmission is both costly to hospital systems and detrimental to patients given the notable increased mortality after readmission across a wide spectrum of acute medical and surgical illnesses.<sup>2</sup> Understanding the drivers of unplanned readmission are of paramount importance in order to develop strategies to mitigate this risk.

Hospital length of stay is a potentially modifiable factor for unplanned hospital readmission given that a longer length of

stay may increase the risk of in-hospital complications, such as acquired nosocomial infections<sup>3</sup> and deconditioning,<sup>4</sup> particularly in elderly patients with multiple comorbidities. Length of stay has gained increasing attention as healthcare systems move from global fixed budgets to bundled fixed payments for acute medical illnesses.<sup>5</sup> However, this transition may promote financial constraints that inadvertently incentivize shorter length of stay so as to minimize costs.<sup>6</sup> Recent reports in elderly patients with acute heart failure<sup>7</sup> and ST segment elevation myocardial infarction<sup>8</sup> demonstrate that

From the Institute for Clinical Evaluative Sciences, Toronto (M.S., F.Q., P.C.A., D.T.K., A.C., V.P., D.S.L., H.C.W.); Institute for Health Policy, Management, and Evaluation, Toronto (P.C.A., D.T.K., D.S.L., H.C.W.); Sunnybrook Health Sciences Centre, Toronto (D.T.K., A.C., H.C.W.); Vancouver General Hospital and St. Paul's Hospital, University of British Columbia, Vancouver (D.W.); Peter Munk Cardiac Centre of the University Health Network, Toronto (D.S.L.); Schulich Heart Research Program, Sunnybrook Research Institute, Toronto, Canada (P.C.A., D.T.K., H.C.W.).

Accompanying Tables S1 through S7 are available at <http://jaha.ahajournals.org/content/6/4/e005460/DC1/embed/inline-supplementary-material-1.pdf>

**Correspondence to:** Harindra C. Wijeyesundera, MD, PhD, FRCPC, FCCS, 2075 Bayview Ave, Ste A202, Toronto, Ontario, Canada M4N 3M5. E-mail: [harindra.wijeyesundera@sunnybrook.ca](mailto:harindra.wijeyesundera@sunnybrook.ca)

Received January 6, 2017; accepted March 7, 2017.

© 2017 The Authors. Published on behalf of the American Heart Association, Inc., by Wiley. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

both short and long length of stay are associated with increased early readmission risk and adverse outcomes, potentially attributed to inappropriate transitional care or residual or untreated medical illness at the time of early discharge. Thus, further understanding of the association between hospital length of stay and readmission is warranted, especially for high-risk populations.

The incidence of severe and symptomatic aortic stenosis is rising as the population ages.<sup>9</sup> Transcatheter aortic valve replacement (TAVR) is currently the preferred treatment over surgical aortic valve replacement in inoperable and high-risk patients.<sup>10</sup> Readmission post-TAVR is common, costly, and associated with increased mortality risk.<sup>11</sup> There are a paucity of data on the relationship between length of stay post-TAVR and readmission. Shortening length of stay is attractive to healthcare systems given that it may potentially reduce adverse outcomes and TAVR-related costs given that a substantial burden of the cost of TAVR is incurred after the index procedure.<sup>12</sup> Accordingly, we conducted a retrospective multicenter cohort study of elective patients undergoing transfemoral TAVR in Ontario, Canada, in order to determine the relationship between length of stay and readmission risk. Specifically, we sought to determine whether the relationship was nonlinear and hypothesized that it was U-shaped with an increased readmission risk with both short and long lengths of stay.

## Methods

Research ethics board approval was obtained from Sunnybrook Health Sciences Centre (Toronto, Ontario, Canada). Given the data sources used for the analyses as outlined below, the need for patient consent was waived under Ontario's Personal Health Information Protection Act.

## Study Population

We conducted a retrospective multicenter cohort study in Ontario, Canada. Ontario is Canada's largest province, with a population of  $\approx$ 13.6 million, all of whom are provided universal medical coverage, which is publicly funded through a single third-party payer, the Ministry of Health and Long Term Care (MOHLTC). All adult patients who underwent TAVR between January 1, 2007 and March 31, 2014 were identified using the Cardiac Care Network (CCN) of Ontario Cardiac Registry, which captures all TAVR referrals to any of the 10 tertiary cardiac centers within the province. The registry contains data on patient demographics and comorbidities, as well as periprocedural and intraoperative details. Over this time period, all TAVI procedures conducted in Ontario were under general anesthesia. We excluded patients who

underwent nonelective TAVR, defined as having had an acute decompensation necessitating an urgent in-patient procedure. Additional exclusions were patients who underwent nontransfemoral TAVR, died in hospital, were transferred to or from another acute care facility, and those under the age of 65 years, for whom information on drug coverage was not available (see below). Finally, we also excluded patients with outlier length of stays beyond the 99th percentile, which, in our study, corresponded to a length of stay longer than 28 days.

## Data Sources

Clinical data from CCN Cardiac Registry were linked to administrative databases using unique encoded identifiers and analyzed at the Institute for Clinical Evaluative Sciences (ICES) to protect patient confidentiality. These databases included the Canadian Institute for Health Information Discharge Abstract Database (CIHI-DAD),<sup>13</sup> which contains information on all hospitalizations including information on discharges, transfers, and deaths. Using the CCN Cardiac Registry, CIHI-DAD, the Ontario Diabetes Database<sup>14</sup> (which contains information on incident and prevalent cases of diabetes mellitus), and Ontario Hypertension Database<sup>15</sup> (which contains information on incident and prevalent cases of hypertension), we identified patient demographics as well as comorbidities within 3 years pre-TAVR using the cardiac and noncardiac diagnosis codes presented in Tables S1 and S2. Frailty was ascertained by the presence of 1 of 12 clusters of frailty-defining diagnoses defined by the Johns Hopkins Adjusted Clinical Groups predictive model.<sup>16</sup> Further linkages were performed to the CIHI Same Day Surgery Database (CIHI-SDS), and the Ontario Health Insurance Plan (OHIP) physician claims database, which, along with the CIHI-DAD, were utilized to identify diagnostic, interventional, and surgical cardiac procedures occurring within the 10 years pre-TAVR (Table S3).<sup>17,18</sup> Socioeconomic status was determined by using the median neighborhood income of the patient's place of residence at the time of referral in accord with their postal code. Preadmission and discharge prescription medication use within 90 days of hospitalization was ascertained by linkage to the Ontario Drug Benefit Database, which contains drug data on all patients above the age of 65 years, for whom full coverage is provided. In-hospital complications post-TAVR included acute kidney injury,<sup>19</sup> bleeding classified as life-threatening, disabling or major bleeding versus minor bleeding<sup>17</sup> in accord with the Valve Academic Research Consortium-2 (VARC-2)<sup>20</sup> criteria, and stroke of any subtype; these events were identified using the CIHI-DAD<sup>21</sup> (coded as an in-hospital complication during the index TAVR admission), CIHI-SDS, and OHIP databases (Table S4). Death was ascertained from linkage to the Registered Persons Database.

## Primary Exposure

Our primary exposure variable was the length of stay during the index admission for elective transfemoral TAVR. We defined length of stay as the days elapsed between the date of TAVR and the date of discharge encoded within the CCN TAVR Registry. Patients undergoing elective TAVR are all admitted on either the day of the procedure or the day before, based on institutional practice. Because such practice was not clinically driven, we did not incorporate the preprocedural period into the length of stay metric given that our study focused on elective patients.

## Outcomes

Primary outcomes of interest were all-cause hospital readmissions occurring within 30 days and 1 year ascertained by linkage to the CIHI-DAD. In sensitivity analysis (see below), readmissions were classified as cardiovascular and noncardiovascular based on the most responsible diagnosis code (Table S5).<sup>21</sup> All outcomes were measured from the date of discharge.

## Statistical Analysis

We modeled the effect of length of stay on the hazard of hospital readmission, treating mortality as a competing event.<sup>22,23</sup> To do so, we used marginal cause-specific Cox proportional hazard models, with a robust (sandwich-type) variance estimator in order to account for the clustering of patients within each of the 10 TAVR centers across the province. Length of stay was initially modeled as a continuous variable with restricted cubic splines with 3 knots at the 10th, 50th and 90th percentile (3, 6, and 13 days, respectively). A Wald test was utilized to test the null hypothesis that the relationship between length of stay and the hazard of readmission was linear. In the absence of evidence of nonlinearity, length of stay was modeled as having a linear relationship with the log-hazard of the outcome.

Multivariable models were adjusted for candidate baseline and procedural variables, which were chosen based on clinical relevance. In order to avoid colinearity with our primary exposure variable, variance inflation factors were calculated, and candidate predictor variables were excluded from the multivariable model if the variance inflation factor was greater than 5. Models for the hazard of readmission within 30 days were adjusted for age, sex, frailty, left ventricular ejection fraction, peripheral vascular disease, cerebral vascular disease, chronic obstructive pulmonary disease, serum creatinine, recent heart failure hospitalization within 90 days, and calendar year of TAVR. Models for the hazard of readmission within 1 year were adjusted for these baseline variables as well as postdischarge warfarin use within 90 days. We

conducted several sensitivity analyses. First, readmissions were classified as cardiovascular and noncardiovascular (Table S5),<sup>21</sup> and each was modeled separately within 30 days and 1 year. Second, given the technological and clinical advances in TAVR over the period of our study, we built an additional model, incorporating an interaction term between period of TAVR implant and length of stay. We chose 2012 as the cutoff between the early and contemporary periods, because this was the year where TAVR received regulatory approval in Canada. Finally, we excluded patients who experienced a TAVR-related complication (transfusion requirement, any bleeding, stroke, transient ischemic attack, need for permanent pacemaker, or acute kidney injury requiring dialysis) from the regression model. A 2-sided  $P < 0.05$  was considered statistically significant. All analyses were performed using SAS software (version 9.3; SAS Institute, Inc, Cary, NC).

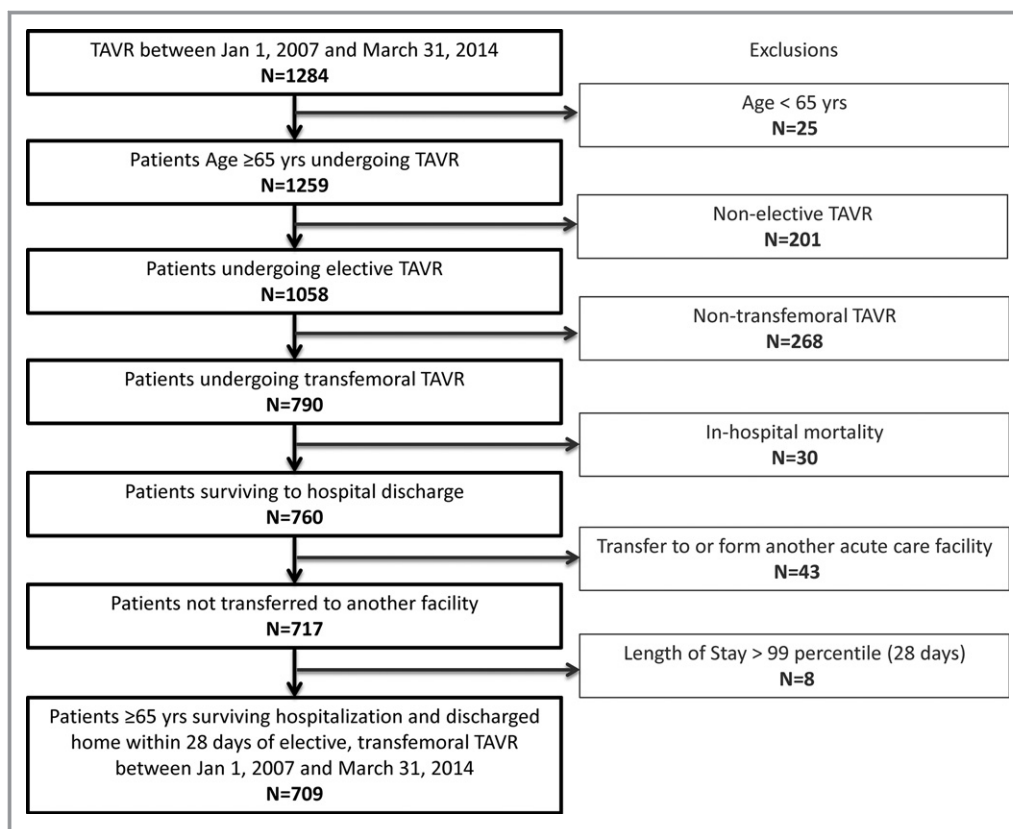
## Results

### Baseline Characteristics

We identified 709 patients over the age of 65 who underwent elective transfemoral TAVR and who survived their index hospitalization and were discharged home. Exclusions are shown in Figure 1. Baseline and procedural characteristics are presented in Table 1. Median age of our cohort was 84 years (interquartile range [IQR], 79–87) and 42% were female. A history of heart failure was the most prevalent cardiac comorbidity (89%). Within the cohort, 26% had a reduced left ventricular ejection fraction and 69% were moderately to severely symptomatic (New York Heart Association [NYHA], III–IV). A history of coronary artery bypass grafting was present in 34% of patients, 12% of patients had a preexisting permanent pacemaker, and 19.5% were classified as frail. The CoreValve was the most frequently implanted prosthesis (52%), followed by the Sapien or Sapien XT, which was implanted in 44% of patients. A comparison of baseline characteristics between survivors of elective transfemoral TAVR hospitalization with those who died in-hospital postprocedure are available in Table S6. Baseline and procedural characteristics were similar across these 2 groups.

### Distribution of Post-Transcatheter Aortic Valve Replacement Length of Stay and In-Hospital Complications

The distribution of length of stay from date of TAVR to date of discharge is presented in Figure 2. Post-TAVR length of stay was positively/right-skewed. Median post-TAVR length of stay was 6 days (IQR, 4–8) and the mean was 7.1 days (SD, 4.6). Five percent of patients were discharged by day 2 post-TAVR



**Figure 1.** Flow diagram. TAVR indicates transcatheter aortic valve replacement.

whereas 18% were discharged by day 3. In contrast, 5% of patients had a length of stay greater than 17 days and 10% had a length of stay greater than 13 days.

Twenty-four percent of patients received a blood transfusion while in-hospital, with 6% having a life-threatening, disabling, or major bleeding and 5% having minor bleeding. Permanent pacemakers were implanted in 14% of patients during the postoperative period. The proportion of patients with a stroke or transient ischemic attack (1.4%) and acute kidney injury requiring dialysis (<1%) was low.

### Readmission Outcomes and Length of Stay

The proportion of patients that were readmitted for any cause within 30-days was 13.5%. Mortality within 30 days in this cohort of elective transfemoral TAVR patients who survived to hospital discharge was low, at <1%. Median 30-day readmission length of stay was 5 days (IQR, 3–11), and the mean was 9.6 days (SD, 15.1). There was no statistically significant difference between mean ( $P=0.273$ ) and median ( $P=0.166$ ) post-TAVR length of stay when comparing patients who were readmitted within 30 days to those who were not (Table 2). When patients were stratified above and below the median post-TAVR hospital length of stay, the proportion of patients readmitted at 30 days was significantly higher ( $P=0.049$ ) after

a longer length of stay ( $\geq 6$  days) when compared with a short post-TAVR length of stay (<6 days). Although the mean and median readmission length of stay was longer in patients with a longer post-TAVR length of stay, this did not reach statistical significance ( $P=0.151$  for mean and  $P=0.239$  for median; Table 3).

The proportion of patients that were readmitted within 1 year was 44.0%, whereas 1-year mortality was 10.6%. Median 1-year readmission length of stay was 5 days (IQR, 3–9), and the mean was 8.8 days (SD, 13.9). Both mean and median post-TAVR length of stay of patients who were readmitted at 1 year was significantly longer than mean and median post-TAVR length of stay of patients that were not readmitted over the same time frame (both  $P<0.001$ ; Table 2). When compared with a short post-TAVR length of stay, more patients were readmitted by 1 year with significantly longer readmission mean and median length of stays after a longer initial post-TAVR length of stay ( $P<0.001$  for both; Table 3).

### Association Between Post-Transcatheter Aortic Valve Replacement Length of Stay and Readmissions

The association between post-TAVR length of stay and the hazard of all-cause readmissions is presented in Figure 3 (for

**Table 1.** Baseline and Procedural Characteristics

Baseline and Procedural Characteristics	All Patients (N=709)
<b>Demographic characteristics</b>	
Age, median, y (IQR)	84 (79–87)
Female, n (%)	300 (42.3)
<b>Socioeconomic status (%)</b>	
1st Quintile (lowest)	124 (17.5)
2nd Quintile	135 (19.0)
3rd Quintile	138 (19.5)
4th Quintile	149 (21.0)
5th Quintile (highest)	159 (22.4)
Missing	SC
<b>Cardiac history (%)</b>	
Past myocardial infarction	224 (31.6)
Ischemic heart disease	514 (72.5)
History of heart failure	632 (89.1)
Heart failure hospitalization within 90 days	127 (17.9)
<b>New York Heart Association Class</b>	
I and II	107 (15.1)
III and IV	474 (66.8)
Missing	128 (18.1)
<b>Left ventricular ejection fraction</b>	
≤50%	183 (25.8)
>50%	514 (72.5)
Missing	12 (1.7)
<b>Past cardiac surgery, n (%)</b>	
Coronary artery bypass grafting	244 (34.4)
Aortic valve replacement	65 (9.2)
Mitral valve replacement or repair	16 (2.3)
Tricuspid valve replacement or repair	SC
History of percutaneous coronary intervention	247 (34.8)
History of implantable cardiac defibrillator	12 (1.7)
History of permanent pacemaker	87 (12.3)
Atrial fibrillation/flutter	228 (32.2)
<b>Comorbid noncardiac conditions (%)</b>	
Diabetes mellitus	326 (46.0)
Hypertension	678 (95.6)
Hyperlipidemia	510 (71.9)
Peripheral vascular disease	90 (12.7)
Cerebrovascular disease	126 (17.8)
Chronic obstructive pulmonary disease	104 (14.7)
History of cancer	55 (7.8)
Cognitive impairment/dementia	12 (1.7)

Continued

**Table 1.** Continued

Baseline and Procedural Characteristics	All Patients (N=709)
Dialysis	23 (3.2)
Frailty	138 (19.5)
<b>Preprocedural blood work (%)</b>	
<b>Serum creatinine</b>	
<120 μmol/L	486 (68.5)
120 to 200 μmol/L	143 (20.2)
≥200 μmol/L	31 (4.4)
Missing	49 (6.9)
<b>Hemoglobin status</b>	
Anemia*	448 (63.2)
Missing	68 (9.6)
<b>Preprocedural echocardiographic parameters</b>	
Mean transvalvular gradient, mean (SD), mm Hg <sup>†</sup>	46 (15)
<b>Preprocedural risk score</b>	
Society of Thoracic Surgeons score, mean (SD), % <sup>‡</sup>	13 (12)
<b>Procedural characteristics (%)</b>	
<b>Year of transfemoral aortic valve replacement</b>	
2007	9 (1.3)
2008	11 (1.6)
2009	39 (5.5)
2010	72 (10.2)
2011	132 (18.6)
2012	147 (20.7)
2013	228 (32.2)
2014	71 (10.0)
<b>Prosthesis type</b>	
Edwards Sapien	312 (44.0)
Corevalve	368 (51.9)
Missing	24 (3.4)
Other	SC
Valve-in-valve	33 (4.7)

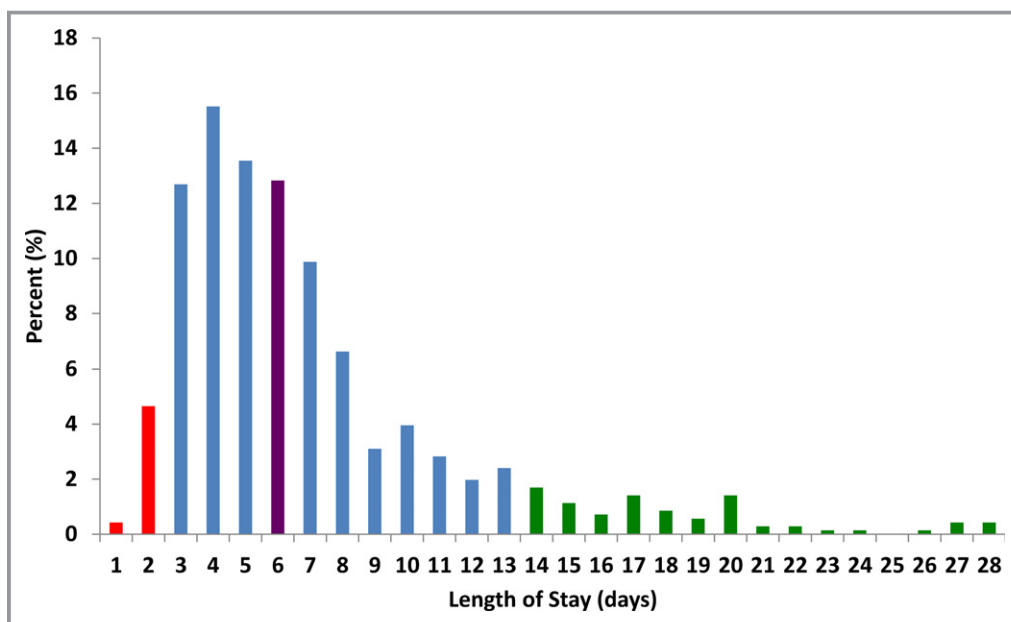
SC indicates small cell, in which patient numbers ≤5 and cannot be released because of privacy regulations; IQR, interquartile range.

\*Men <140 g/L and female <120 g/L.

<sup>†</sup>n=90 (12.5%) missing.

<sup>‡</sup>n=458 (64.6%) missing.

30-day readmission) and Figure 4 (for 1-year readmission). In each figure, we describe the relative increase in the hazard of readmission for a given length of stay compared with a patient with the median post-TAVR length of stay of 6 days. In the unadjusted analysis, there was no significant association between post-TAVR length of stay and the hazard of readmission within 30 days ( $P=0.125$ ). However, there was



**Figure 2.** Distribution of length of stay post-TAVR. The proportion of patients for each length of stay post-TAVR is depicted. The lower 10th percentile is depicted in red and the upper 90th percentile in green. Median length of stay is depicted in purple. TAVR indicates transcatheter aortic valve replacement.

a significant association between post-TAVR length of stay and the hazard of readmission within 1 year ( $P < 0.001$ ), which was linear ( $P = 0.110$  for nonlinearity). Patients with the shortest post-TAVR length of stay had the lowest readmission risk, and those with the longest post-TAVR length of stay had the highest readmission risk. After adjustment for baseline covariates (Table S7), there remained no significant association between post-TAVR length of stay and the hazard of readmission within 30 days ( $P = 0.925$ ). Furthermore, after multivariable adjustment, post-TAVR length of stay demonstrated a significant association with the hazard of readmission within 1 year ( $P = 0.010$ ) that remained linear ( $P = 0.549$  for nonlinearity). There was a 3% increase in the adjusted hazard of readmission within 1 year (hazard ratio = 1.03; 95% CI, 1.01–1.05;  $P = 0.005$ ) for every additional day spent in-hospital post-TAVR.

### Sensitivity Analysis

Within 30 days, 3.6% ( $n = 26$ ) of patients had a cardiovascular readmission and 10.5% ( $n = 75$ ) had a noncardiovascular

readmission. Consistent with the primary outcome, there was no significant association between post-TAVR length of stay and either cardiovascular ( $P = 0.463$  unadjusted and  $P = 0.540$  adjusted) or noncardiovascular readmission ( $P = 0.204$  unadjusted and  $P = 0.766$  adjusted) within 30 days. At 1 year, 16% ( $n = 111$ ) of patients had a cardiovascular readmission and 38% ( $n = 273$ ) had a noncardiovascular readmission. After multivariable adjustment, there was a linear association between post-TAVR length of stay and the hazards of cardiovascular ( $P = 0.036$  for overall association and  $P = 0.579$  for nonlinearity) and noncardiovascular readmissions ( $P = 0.009$  for overall association and  $P = 0.477$  for nonlinearity) at 1 year. There was no evidence of a U-shaped association for either outcome. As post-TAVR length of stay increased, risk of cardiovascular and noncardiovascular readmission increased, whereas those with the shortest post-TAVR length of stay had the lowest readmission risk. Thirty-seven percent of the cohort underwent TAVR before 2012. There was no statistically significant interaction between period of TAVR (ie, pre- or post-2012) and post-TAVR length of stay for 30-day ( $P = 0.776$  for interaction) and

**Table 2.** Post-TAVR Length of Stay Stratified by Readmission Status

Post-TAVR Length of Stay (Days)	30-Day All-Cause Readmission			1-Year All-Cause Readmission		
	Not Readmitted	Readmitted	<i>P</i> Value	Not Readmitted	Readmitted	<i>P</i> Value
Mean (SD)	7.0 (4.6)	7.5 (4.8)	0.273	6.5 (4.1)	7.8 (5.2)	<0.001
Median (IQR)	6 (4–8)	6 (4–10)	0.166	5 (4–8)	6 (4–10)	<0.001

IQR indicates interquartile range; TAVR, transcatheter aortic valve replacement.

**Table 3.** Readmission Length of Stay Stratified by Short and Long Post-TAVR Length of Stay

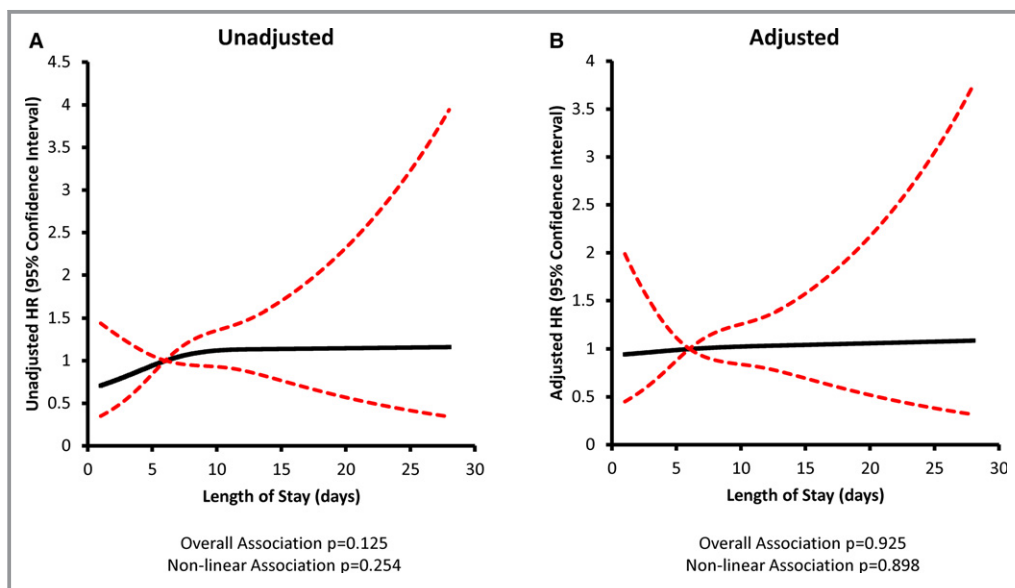
	Index TAVR Hospitalization			P Value
	All Patients (N=709)	Length of Stay <6 Days (N=332)	Length of Stay ≥6 Days (N=377)	
<b>30-day all-cause readmission</b>				
Proportion readmitted, n (%)	96 (13.5)	36 (10.8)	60 (15.9)	0.049
Readmission length of stay, days, median (IQR)	5 (3–11)	4 (3–8)	6 (3–13)	0.239
Readmission length of stay, days, mean (SD)	9.6 (15.1)	6.8 (6.1)	11.4 (18.4)	0.151
<b>1-year all-cause readmission</b>				
Proportion readmitted, n (%)	397 (44.0)	126 (38.0)	186 (49.3)	0.002
Readmission length of stay, days, median (IQR)	5 (3–9)	4 (3–7)	6 (3–12)	<0.001
Readmission length of stay, days, mean (SD)	8.8 (13.9)	5.6 (5.5)	11.0 (17.1)	<0.001

IQR indicates interquartile range; TAVR, transcatheter aortic valve replacement.

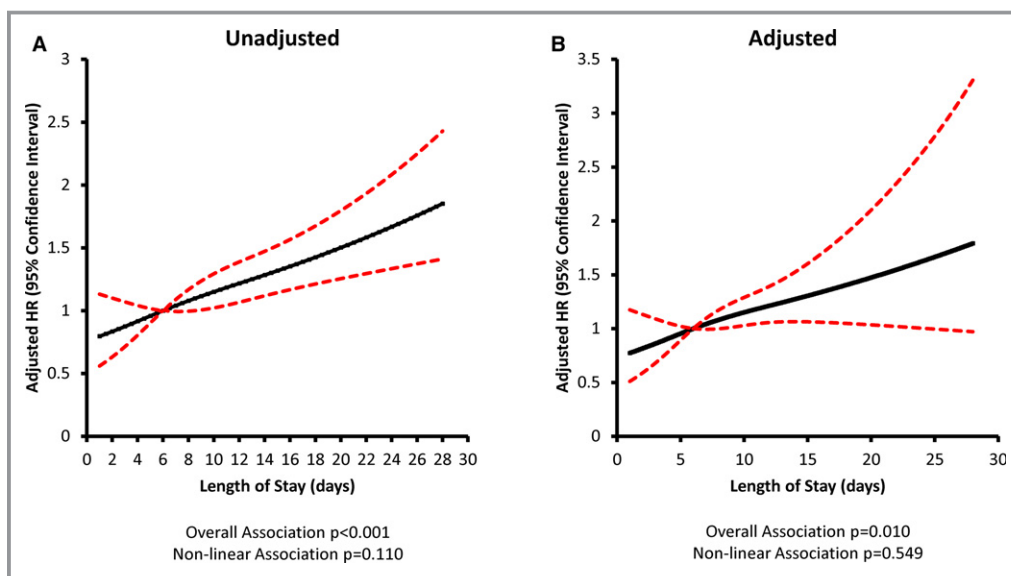
1-year ( $P=0.884$  for interaction) readmission risk models. When 277 patients experiencing in-hospital complications were excluded from the model, results remained similar. After adjustment, there was no association between post-TAVR length of stay and 30-day readmission risk ( $n=49/432$  [11.3%] readmitted;  $P=0.829$  for overall association). However, there was an association between post-TAVR length of stay and 1-year readmissions ( $n=179/432$  [41.4%] readmitted;  $P=0.005$  for overall association), which was linear ( $P=0.948$  for nonlinearity).

## Discussion

In this multicenter cohort study, we initially hypothesized that both a short and long hospital length of stay after elective transfemoral TAVR would be associated with an increased readmission risk. We found both 30-day (13.5%) and 1-year (44.0%) readmission rates were high. However, we did not detect a significant increase in 30-day or 1-year readmission risk for shorter post-TAVR lengths of stay. In fact, post-TAVR length of stay was not associated with 30-day readmission even after multivariable adjustment and when cardiovascular



**Figure 3.** Post-TAVR length of stay and 30-day all-cause readmission risk. (A) Unadjusted and (B) adjusted models are depicted with length of stay modeled as a restricted cubic spline with knots at 3, 6, and 13 days. All models accounted for correlation within hospitals. Risk adjustment included age, sex, frailty, left ventricular ejection fraction, peripheral vascular disease, cerebral vascular disease, chronic obstructive pulmonary disease, serum creatinine, recent heart failure hospitalization within 90 days, and year of TAVR. HR indicates hazard ratio; TAVR, transcatheter aortic valve replacement.



**Figure 4.** Post-TAVR length of stay and 1-year all-cause readmission risk. (A) Unadjusted and (B) adjusted models are depicted with length of stay modeled as a restricted cubic spline with knots at 3, 6, and 13 days. All models accounted for correlation within hospitals. Risk adjustment included age, sex, frailty, left ventricular ejection fraction, peripheral vascular disease, cerebral vascular disease, chronic obstructive pulmonary disease, serum creatinine, recent heart failure hospitalization within 90 days, year of TAVR, and warfarin use within 90 days of discharge. HR indicates hazard ratio; TAVR, transcatheter aortic valve replacement.

and noncardiovascular readmissions were considered separately. In contrast, we found a linear association between post-TAVR length of stay and 1-year readmission risk. The 1-year readmission risk was highest in patients with the longest post-TAVR length of stay, and for each additional day in hospital after elective transfemoral TAVR, risk of all-cause readmission increased by 3%. This association was consistent across both cardiovascular and noncardiovascular readmissions at 1 year.

In our cohort, post-TAVR length of stay was not a marker for heightened 30-day readmission risk, which is in contrast to other cardiac diseases, such as acute heart failure<sup>7</sup> and myocardial infarction.<sup>8</sup> This may be explained by our exclusion of nonelective patients. It is plausible that the preoperative clinical stability of the cohort selected for a lower-risk group of patients who were not subjected to a high-risk procedure amidst a systemic inflammatory state, and these patients had not accrued a significant number of days in hospital preoperatively. As a result, they may have been less likely to have (1) already incurred significant deconditioning preoperatively, (2) succumb to significant deconditioning postoperatively, or (3) been exposed to procedures and interventions that place them at risk of nosocomial infections. Alternatively, given the extensive and often prolonged preprocedural work-up period, it maybe that there is greater attention to planning and establishing appropriate transitional care, such as homecare or rehabilitation in anticipation of the TAVR

procedure. Indeed, such transition of care measures have been found to be effective methods of mitigating readmission risk.<sup>24–26</sup> Further study of the impact of transitional care on readmission risk is warranted. In contrast, the association with increasing length of stay and heightened readmission risk at 1 year may have been a marker of the underlying complex cardiac disease and comorbidities common to high-risk and inoperable patients with severe aortic stenosis, rather than a proxy for the index procedure and care delivered during the index hospitalization. Therefore, our data are in support of strategies directed toward shortening post-TAVR length of stay.

Our findings are in keeping with 3 recently published single-center studies. The first reported on a quality improvement initiative for 393 patients surviving hospitalization for transfemoral TAVR between 2012 and 2014 in Canada, of whom 150 were enrolled in a clinical pathway targeting discharge within 48 hours.<sup>27</sup> This study found that the proportion of 30-day readmission was not significantly different between the strategy targeting discharge within 48 hours and the standard discharge strategy. The second reported on 424 patients surviving transfemoral TAVR with the SAPIEN-XT prosthesis between 2009 and 2013 in the United States.<sup>28</sup> When compared to patients discharged greater than 72 hours post-TAVR, early discharge within 72 hours was not associated with a significantly higher proportion of patients readmitted or dying within 30 days.



Finally, a study from Italy reported on 465 patients surviving hospitalization for transfemoral TAVR between 2007 and 2014.<sup>29</sup> After 2:1 propensity matching of patients discharged after 72 hours with patients discharge within 72 hours, the final cohort of 267 patients had a low 30-day readmission rate (1.1%) without a significant difference in readmission or mortality between the 2 groups. Our multicenter, population-level study complements the current evidence suggesting that early discharge may be safe, without an increase in readmission risk. Moreover, rather than predefining a specific cutoff for early discharge, we modeled the length of stay in its entirety. Regardless of whether 48 or 72 hours is considered, and after multivariable adjustment, we found that shorter length of stay is not associated with an increased readmission risk.

Our results have several important implications. There exists no consensus on the optimal length of stay in patients undergoing elective transfemoral TAVR, and this issue is not addressed in guideline statements.<sup>10</sup> TAVR is a complex intervention targeted toward elderly patients with aortic stenosis, who, in addition to their inoperability or high-risk surgical status, have multiple interacting medical comorbidities that may pose barriers to early discharge from hospital and predispose them to early readmission. Our results, however, reinforce that a shorter length of stay after elective TAVR may not be associated with harm and support initiatives directed toward shortening length of stay. Furthermore, TAVR remains costly, and despite the growing number of suitable candidates for intervention, it remains restricted to specialized tertiary care centers. Given that a substantial portion of the costs associated with TAVR are incurred during the time spent in-hospital after the index procedure,<sup>12</sup> shortening post-TAVR length of stay holds promise in reducing costs and improving the efficiency of care without compromising quality of care, namely early readmission.<sup>1</sup> Lastly, the high observed 30-day (13.5%) and 1-year (44.0%) readmission rates noted in elective cases highlights the need to develop strategies aimed at reducing readmission risk such as postdischarge transitional care and early physician follow-up.<sup>25,30</sup>

Our study should be interpreted in the context of several limitations that merit discussion. Since 2014, advances in technology, including reductions in catheter size, improvement in delivery systems, and increasing use of conscious sedation rather than general anesthesia, may limit the generalizability of our findings. However, the lack of association between a short length of stay post-TAVR and readmission is still reassuring given that such advances are likely to promote earlier discharge, which appears safe and feasible. This study was not a randomized trial and therefore cannot inform on the optimal length of stay for patients undergoing elective transfemoral TAVR. It is possible that our study was underpowered to detect an association between length of

stay and 30-day readmissions. We excluded patients with an extremely prolonged length of stay greater than 28 days (ie, <99th percentile of the cohort); however, it is likely that these extreme outliers are noninformative to the general cohort of elective TAVR patients. Finally, despite adjustment for multiple covariates, we cannot rule out residual confounding that may have biased our results.

In conclusion, readmission rates after elective transfemoral TAVR remains high. However, there does not appear to be an increased risk of readmissions in patients with a short length of stay after elective transfemoral TAVR. Longer length of stay is associated with increased late readmission risk. These results support the safety of early discharge after elective transfemoral TAVR and highlight the need for prospective studies evaluating the optimal timing of discharge.

## Acknowledgments

The authors acknowledge that the clinical registry data used in this publication are from CCN and its participating hospitals. CCN serves as an advisory body to the MOHLTC and is dedicated to improving the quality, efficiency, access, and equity of adult cardiovascular services in Ontario, Canada. CCN is funded by the MOHLTC.

## Sources of Funding

This study is funded by a Grant-in-Aid from the Heart and Stroke Foundation of Canada. Dr Wijeyesundera had full access to all of the data in the study and takes responsibility for the integrity of the data and accuracy of the data analysis. This study was supported by the Institute for Clinical Evaluative Science (ICES), which is funded by an annual grant from the Ontario Ministry of Health and Long-Term Care (MOHLTC). The opinions, results and conclusions reported in this article are those of the authors and are independent from the funding sources. No endorsement by ICES or the Ontario MOHLTC is intended or should be inferred. Parts of this material are based on data and information compiled and provided by the Canadian Institute for Health Information. However, the analyses, conclusions, opinions, and statements expressed herein are those of the authors, and not necessarily those of the Canadian Institute for Health Information. Dr Wijeyesundera is supported by a Distinguished Clinical Scientist Award from the Heart and Stroke Foundation of Canada. Drs Ko and Lee are supported by a mid-career personnel award from the Heart and Stroke Foundation, Ontario Provincial Office. Dr Lee is the Ted Rogers Chair in Heart Function Outcomes, a joint Hospital-University Chair of the University Health Network and the University of Toronto. Dr Austin is supported, in part, by a Heart and Stroke Foundation (Ontario office) Career Investigator Award. Dr Czarnecki is supported by a Canadian Institute of Health Research Fellowship Award.

## Disclosures

Dr Wijesundera and Dr Wood received research funding from Edwards Lifesciences. Dr Wijesundera received research funding from Medtronic Inc.

## References

- Ashton CM, Del Junco DJ, Soucek J, Wray NP, Mansyur CL. The association between the quality of inpatient care and early readmission: a meta-analysis of the evidence. *Med Care*. 1997;35:1044–1059.
- Jencks SF, Williams MV, Coleman EA. Rehospitalizations among patients in the Medicare fee-for-service program. *N Engl J Med*. 2009;360:1418–1428.
- Hauck K, Zhao X. How dangerous is a day in hospital? A model of adverse events and length of stay for medical inpatients. *Med Care*. 2011;49:1068–1075.
- Wu HY, Sahadevan S, Ding YY. Factors associated with functional decline of hospitalised older persons following discharge from an acute geriatric unit. *Ann Acad Med Singapore*. 2006;35:17–23.
- Mechanic R, Tompkins C. Lessons learned preparing for Medicare bundled payments. *N Engl J Med*. 2012;367:1873–1875.
- Ackerly DC, Grabowski DC. Post-acute care reform—beyond the ACA. *N Engl J Med*. 2014;370:689–691.
- Sud M, Yu B, Austin PC, Wijesundera HC, Ko DT, Cram P, Domanski P, Lee DS. Association between short and long length of stay with 30-day readmission and mortality in hospitalized patients with heart failure. *Eur Heart J*. 2016;37(suppl):194–195.
- Swaminathan RV, Rao SV, McCoy LA, Kim LK, Minutello RM, Wong SC, Yang DC, Saha-Chaudhuri P, Singh HS, Bergman G, Feldman DN. Hospital length of stay and clinical outcomes in older STEMI patients after primary PCI: a report from the National Cardiovascular Data Registry. *J Am Coll Cardiol*. 2015;65:1161–1171.
- Martinsson A, Li X, Andersson C, Nilsson J, Smith JG, Sundquist K. Temporal trends in the incidence and prognosis of aortic stenosis: a nationwide study of the Swedish population. *Circulation*. 2015;131:988–994.
- Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP III, Guyton RA, O’Gara PT, Ruiz CE, Skubas NJ, Sorajja P, Sundt TM III, Thomas JD; Members AATF. 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 Practice Guidelines. *Circulation*. 2014;129:e521–e643.
- Nombela-Franco L, del Trigo M, Morrison-Polo G, Veiga G, Jimenez-Quevedo P, Abdul-Jawad Altisent O, Campelo-Parada F, Biagioni C, Puri R, DeLarocheliere R, Dumont E, Doyle D, Paradis JM, Quiros A, Almeria C, Gonzalo N, Nunez-Gil I, Salinas P, Mohammadi S, Escaned J, Fernandez-Ortiz A, Macaya C, Rodes-Cabau J. Incidence, causes, and predictors of early (<math>\leq 30</math> days) and late unplanned hospital readmissions after transcatheter aortic valve replacement. *JACC Cardiovasc Interv*. 2015;8:1748–1757.
- Wijesundera HC, Li L, Braga V, Pazhaniappan N, Pardhan AM, Lian D, Leeksma A, Peterson B, Cohen EA, Forsey A, Kingsbury KJ. Drivers of healthcare costs associated with the episode of care for surgical aortic valve replacement versus transcatheter aortic valve implantation. *Open Heart*. 2016;3:e000468.
- Juurink D, Preyra C, Croxford R, Chong A, Austin PC, Tu JV, Laupacis A. *Canadian Institute for Health Information Discharge Abstract Database: A Validation Study*. Toronto, Ontario: Institute for Clinical Evaluative Sciences; 2006.
- Hux JE, Ivis F, Flintoft V, Bica A. Diabetes in Ontario: determination of prevalence and incidence using a validated administrative data algorithm. *Diabetes Care*. 2002;25:512–516.
- Tu K, Campbell NR, Chen ZL, Cauch-Dudek KJ, McAlister FA. Accuracy of administrative databases in identifying patients with hypertension. *Open Med*. 2007;1:e18–e26.
- University JH. The Johns Hopkins Adjusted Clinical Groups technical reference guide, version 9. 2009.
- Lee DS, Stukel TA, Austin PC, Alter DA, Schull MJ, You JJ, Chong A, Henry D, Tu JV. Improved outcomes with early collaborative care of ambulatory heart failure patients discharged from the emergency department. *Circulation*. 2010;122:1806–1814.
- Lee DS, Stitt A, Wang X, Yu JS, Gurevich Y, Kingsbury KJ, Austin PC, Tu JV. Administrative hospitalization database validation of cardiac procedure codes. *Med Care*. 2013;51:e22–e26.
- Wald R, Quinn RR, Luo J, Li P, Scales DC, Mamdani MM, Ray JG; University of Toronto Acute Kidney Injury Research G. Chronic dialysis and death among survivors of acute kidney injury requiring dialysis. *JAMA*. 2009;302:1179–1185.
- Kappetein AP, Head SJ, Genereux P, Piazza N, van Mieghem NM, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, van Es GA, Hahn RT, Kirtane AJ, Krucoff MW, Kodali S, Mack MJ, Mehran R, Rodes-Cabau J, Vranckx P, Webb JG, Windecker S, Serruys PW, Leon MB. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. *Eur Heart J*. 2012;33:2403–2418.
- Tu JV, Chu A, Donovan LR, Ko DT, Booth GL, Tu K, Maclagan LC, Guo H, Austin PC, Hogg W, Kapral MK, Wijesundera HC, Atzema CL, Gershon AS, Alter DA, Lee DS, Jackevicius CA, Bhatia RS, Udell JA, Rezai MR, Stukel TA. The cardiovascular health in ambulatory care research team (CANHEART): using big data to measure and improve cardiovascular health and healthcare services. *Circ Cardiovasc Qual Outcomes*. 2015;8:204–212.
- Austin PC, Lee DS, Fine JP. Introduction to the analysis of survival data in the presence of competing risks. *Circulation*. 2016;133:601–609.
- Lee W, Wei LJ, Amato D. *Cox-Type Regression Analysis for Large Numbers of Small Groups of Correlated Failure Time Observations*. Netherlands: Kluwer Academic; 1992.
- Barnason S, Zimmerman L, Nieveen J, Schulz P, Young L. Patient recovery and transitions after hospitalization for acute cardiac events: an integrative review. *J Cardiovasc Nurs*. 2012;27:175–191.
- Frankenstein L, Frohlich H, Cleland JG. Multidisciplinary approach for patients hospitalized with heart failure. *Rev Esp Cardiol (Engl Ed)*. 2015;68:885–891.
- Hall MH, Esposito RA, Pekmezaris R, Lesser M, Moravick D, Jahn L, Blendedman R, Akerman M, Nouryan CN, Hartman AR. Cardiac surgery nurse practitioner home visits prevent coronary artery bypass graft readmissions. *Ann Thorac Surg*. 2014;97:1488–1493; discussion 1493–1485.
- Lauck SB, Wood DA, Baumbusch J, Kwon JY, Stub D, Achtem L, Blanke P, Boone RH, Cheung A, Dvir D, Gibson JA, Lee B, Leipsic J, Moss R, Perlman G, Polderman J, Ramanathan K, Ye J, Webb JG. Vancouver transcatheter aortic valve replacement clinical pathway: minimalist approach, standardized care, and discharge criteria to reduce length of stay. *Circ Cardiovasc Qual Outcomes*. 2016;9:312–321.
- Durand E, Eltchaninoff H, Canville A, Bouhzam N, Godin M, Tron C, Rodriguez C, Litzler PY, Bauer F, Cribier A. Feasibility and safety of early discharge after transfemoral transcatheter aortic valve implantation with the Edwards SAPIEN-XT prosthesis. *Am J Cardiol*. 2015;115:1116–1122.
- Barbanti M, Capranzano P, Ohno Y, Attizzani GF, Gulino S, Imme S, Cannata S, Aruta P, Bottari V, Patane M, Tamburino C, Di Stefano D, Deste W, Giannazzo D, Gargiulo G, Caruso G, Sgroi C, Todaro D, di Simone E, Capodanno D, Tamburino C. Early discharge after transfemoral transcatheter aortic valve implantation. *Heart*. 2015;101:1485–1490.
- Scott IA. Preventing the rebound: improving care transition in hospital discharge processes. *Aust Health Rev*. 2010;34:445–451.

# **Supplemental Material**

**Table S1. Cardiac disease diagnosis codes**

<b>Diagnosis</b>	<b>ICD-9 codes</b>	<b>ICD-10 codes</b>
Heart failure	428	I099,I255,I420,I425,I426,I427,I428,I429,I43, I50,P290
Ischemic heart disease	410-414	I20-I24
Myocardial Infarction	410	I21, I22, I252
Atrial Fibrillation	427.3	I48

ICD- International Classification of Disease

**Table S2. Non-cardiac disease diagnosis codes<sup>1</sup>**

Diagnosis	ICD-9 codes	ICD-10 codes	OHIP	ODBD
Peripheral Vascular Disease	440-448, 785.4	I70,I71,I731,I738,I739,I771,I790,I792,K551,K558,K559,Z958,Z959		
Cerebrovascular Disease	430-438	G45,G46,H340,I60,I61,I62,I63,I64,I65,I66,I67,I68,I69		
Chronic Obstructive Pulmonary Disease	410	I278,I279,J40,J41,J42,J43, J44,J45, J46, J47, J60, J61, J62, J63, J64, J65, J66, J67, J684, J701, J703		
Cognitive Impairment / Dementia	290.0-290.9, 331.0	F00,F01,F02,F03,F051, G30,G311,G041,G114, G801,G802,G81,G82,G830,G831,G832,G833,G834,G839	290, 331, 797	Any cholinesterase inhibitor script in ODB during 1 year prior to index, ODB subclnam =: 'CHOLINESTERASE INHIBITOR'
Metastatic Cancer	196-199	C77-C80		
Non-metastatic Cancer	140-172, 174-195, 200-208	C0, C1, C20-C26, C30-C34, C37-C41, C43, C45-C58, C6, C70-C76, C81-C85, C88, C90-C97		

ICD- International Classification of Disease; OHIP- Ontario Health Insurance Plan; ODBD- Ontario Drug Benefits Database

**Table S3. List of codes for Procedures<sup>2, 3</sup>**

<b>Procedure</b>	<b>CCI (ICD-10) codes</b>	<b>OHIP codes</b>	<b>CCP Codes</b>
Percutaneous coronary intervention	1IJ50, 1IJ54GQAZ, 1IJ57GQ	Z434	48.02, 48.03
Coronary artery bypass surgery	1IJ76	R742, R743	48.1
Mitral Valve Surgery	1HU80, 1HU90	R734-735	47.02, 42.12, 47.22, 47.23
Tricuspid Valve Surgery	1HS80	R728	47.04, 47.14, 47.26, 47.27
Aortic Valve Surgery	1HV80, 1HV90	R738, R863	47.03, 47.13, 47.24, 47.25
Pulmonary Valve Surgery	1HS90, 1HT80 1HT89, 1HT90	R772	47.05, 47.15, 47.28, 47.29
Permanent pacemaker implantation	1HZ53GRNM, 1HZ53LANM, 1HZ53GRNK, 1HZ53LANK, 1HZ53GRNL, 1HZ53LANL, 1HZ53GRFR, 1HZ53LAFR	R752	49.71
Implantable cardiac defibrillator	1HZ53GRFS, 1HZ53LAFS	R761, R753	49.74
Chronic Dialysis (2 codes at least 90 days apart but no more than 150 days separating the first and second code)	1PZ21HQBR 1PZ21HPD4	R849, R850, G323, G325, G326, G330, G331, G332, G860, G333, G083, G091, G085, G295, G082, G090, G092, G093, G094, G861, G862, G863, G864, G865, G866, G294, G095, G096	51.95, 66.98

ICD- International Classification of Disease; CCI- Canadian Classification of Health Interventions; CCP- Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures

**Table S4. In Hospital Complications<sup>1, 3, 4</sup>**

Diagnosis	ICD-9 codes/[CCI Codes]	ICD-10 codes/[CCP Codes]	OHIP
<p><b>Acute Kidney Injury</b></p> <p>A diagnosis code for acute kidney injury with <math>\geq 1</math> code for dialysis during the same hospitalization</p>	<p>Acute Kidney Injury 584.5-584.9, 669.3, 958.5 634.3, 635.3, 636.3, 637.3, 638.3, 639.3</p> <p>Dialysis [51.95, 66.98]</p>	<p>Acute Kidney Injury N17.0-N17.9, O08.4, T79.5, O90.4</p> <p>Dialysis [1PZ21HQBR, 1PZ21HPD4]</p>	<p>Dialysis R849, R850, G323, G325, G326, G330, G331, G332, G860, G333, G083, G091, G085, G295, G082, G090, G092, G093, G094, G861, G862, G863, G864, G865, G866, G294, G095, G096</p>
<p><b>Bleeding (VARC-2)</b></p> <p>Classify as:</p> <p><b>Life-threatening or Disabling or Major Bleeding</b> = Any bleeding code and <math>\geq 2</math> units of blood transfused (Blood=BTREDBC) AND All intracranial bleeding</p> <p><b>Minor Bleeding</b> = Any non-intracranial bleeding code and <math>&lt; 2</math> units of blood transfused (Blood=BTREDBC)</p>		<p>Gastrointestinal I850, K226, K250, K252, K254, K256, K 260, K 262, K264, K266, K270, K272, K274, K276, K280, K284, K286, K290, K625, K661, K920, K921, K922</p> <p>Intracranial I600, I601, I602, I603, I604, I605, I606, I607, I608, I609, I610, I611, I612, I613, I614, I615, I616, I618, I619, I620, I621, I629</p> <p>Urological N020-029, R310, R311, R318</p> <p>Pulmonary Bleeding R040, R041, R042, R048, R049</p> <p>Other Bleeding R58, T810</p>	

**Stroke/TIA**

362.3, 430, 431, 434, 435, 436

I60, I61, I63 (excluding I63.6), I64,  
H34.0, H34.1, G45 (excluding  
G45.4)

---

ICD- International Classification of Disease; CCI- Canadian Classification of Health Interventions; CCP- Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures; VARC-2 Valve Academic Research Consortium 2; TIA – Transient Ischemic Attack



**Table S5. Cause-specific Readmissions<sup>1</sup>**

<b>Diagnosis</b>	<b>ICD-9 codes</b>	<b>ICD-10 codes</b>
Cardiovascular (primary diagnosis)	Acute Myocardial Infarction 410	Acute Myocardial Infarction I21, I22
	Stroke 430, 431, 434, 436, 362.3	Stroke I60, I61, I63 (excluding I63.6), I64, H34.1
	Heart Failure 428	Heart Failure I50
	Hypertension NA	Hypertension I10, I11, I12, I13 or I15
	Unstable Angina 411, 413	Unstable Angina I20
	Ischemic Stroke 434, 436, 362.3	Ischemic Stroke I63, I64, H34.1 (excluding I63.6)
	Hemorrhagic Stroke 430, 431	Hemorrhagic Stroke I60, I61
	Transient Ischemic Attack 435	Transient Ischemic Attack G45 (excluding G45.4), H34.0
	Atrial Fibrillation 427.3	Atrial Fibrillation I48
	Abdominal Aortic Aneurysm 441.3, 441.4	Abdominal Aortic Aneurysm I71.3, I71.4
Peripheral Arterial Disease 440.2, 443.9, 444.2	Peripheral Arterial Disease I70.2, I73.9, I74.3, I74.4	
Non-cardiovascular	Not meeting criteria for Cardiovascular readmission	

ICD- International Classification of Disease

**Table S6. Comparison Between Patients Surviving to Discharge and Dying In-hospital**

Baseline And Procedural Characteristics	Survived Hospitalization (N=709)	Died In Hospital (N=27)	p-value
<b>Demographic Characteristics</b>			
Age, median, yrs (IQR)	84 (79-87)	86 (84-89)	0.061
Female, n (%)	300 (42.3%)	16 (59.3%)	0.081
Socioeconomic Status			
1st Quintile (lowest)	124 (17.5%)	0 (0.0%)	0.553
2nd Quintile	135 (19.0%)	SC	
3rd Quintile	138 (19.5%)	SC	
4th Quintile	149 (21.0%)	6 (22.2%)	
5th Quintile (highest)	159 (22.4%)	SC	
Missing	SC	9 (33.3%)	
<b>Cardiac History</b>			
Prior Myocardial Infarction, n (%)	224 (31.6%)	7 (25.9%)	0.533
Ischemic Heart Disease, n (%)	514 (72.5%)	19 (70.4%)	0.808
History of Heart Failure, n (%)	632 (89.1%)	21 (77.8%)	0.067
Heart Failure Hospitalization within 90 days	127 (17.9%)	SC	0.936
New York Heart Association Class			
I and II	107 (15.1%)	SC	0.303
III and IV	474 (66.8%)	15 (55.6%)	
Missing	128 (18.1%)	SC	
Left Ventricular Ejection Fraction, n (%)			
≤50%	183 (25.8%)	SC	0.031
>50%	514 (72.5%)	22 (81.5%)	
Missing	12 (1.7%)	SC	
Prior Cardiac Surgery, n (%)			
Coronary Artery Bypass Grafting	244 (34.4%)	SC	0.034
Aortic Valve Replacement	65 (9.2%)	SC	0.329
Mitral Valve Replacement or Repair	16 (2.3%)	0 (0.0%)	0.430
Tricuspid Valve Replacement or Repair	SC	0 (0.0%)	0.782
History of Percutaneous Coronary Intervention, n (%)	247 (34.8%)	10 (37.0%)	0.814
History of Implantable Cardiac Defibrillator, n (%)	12 (1.7%)	0 (0.0%)	0.496

History of Permanent Pacemaker, n (%)	87 (12.3%)	SC	0.857
Atrial Fibrillation/Flutter, n (%)	228 (32.2%)	10 (37.0%)	0.595
<b>Co-morbid Non-cardiac Conditions</b>			
Diabetes, n (%)	326 (46.0%)	11 (40.7%)	0.592
Hypertension, n (%)	678 (95.6%)	26 (96.3%)	0.867
Hyperlipidemia, n (%)	510 (71.9%)	15 (55.6%)	0.065
Peripheral Vascular Disease, n (%)	90 (12.7%)	SC	0.376
Cerebrovascular Disease, n (%)	126 (17.8%)	SC	0.372
Chronic Obstructive Pulmonary Disease, n (%)	104 (14.7%)	8 (29.6%)	0.034
History of Cancer, n (%)	55 (7.8%)	SC	0.947
Cognitive Impairment / Dementia, n (%)	12 (1.7%)	0 (0.0%)	0.496
Dialysis, n (%)	23 (3.2%)	SC	0.895
Frailty, n (%)	138 (19.5%)	6 (22.2%)	0.723
<b>Pre-procedural Blood Work</b>			
Serum Creatinine, n (%)			
< 120 µmol/L	486 (68.5%)	6 (22.2%)	0.092
120 - 200 µmol/L	143 (20.2%)	14 (51.9%)	
≥ 200 µmol/L	31 (4.4%)	SC	
Missing	49 (6.9%)	SC	
Hemoglobin Status, n (%)			
Anemia*	448 (63.2%)	14( 51%)	0.150
Missing	68 (9.6%)	6 (22.2%)	
<b>Pre-procedural Echocardiographic Parameters</b>			
Mean transvalvular gradient, mean, mmHg, (SD)†	46 (15)	46 (16)	0.873
<b>Pre-procedural Risk Score</b>			
Society of Thoracic Surgeons Score, mean, %, (SD)‡	13 (12)	18 (11)	0.162
<b>Procedural Characteristics</b>			
Year of Transfemoral Aortic Valve Replacement, n (%)			
2007	9 (1.3%)	SC	0.934
2008	11 (1.6%)	0 (0.0%)	

2009	39 (5.5%)	SC	
2010	72 (10.2%)	SC	
2011	132 (18.6%)	SC	
2012	147 (20.7%)	SC	
2013	228 (32.2%)	8 (29.6%)	
2014	71 (10.0%)	SC	
Prosthesis Type, n (%)			
Edwards Sapien	312 (44.0%)	11 (40.7%)	<.001
Corevalve	368 (51.9%)	11 (40.7%)	
Missing	24 (3.4%)	SC	
Other	SC	SC	
Valve-in-valve, n (%)	33 (4.7%)	SC	0.817

\*Men < 140 g/L and Female < 120 g/L

† n=90 (12.5%) missing

‡ n=458 (64.6%) missing

IQR: interquartile range, SD: standard deviation

SC indicates small cell, in which patient numbers  $\leq 5$  and cannot be released due to privacy regulations

**Table S7. Effect Estimates of Baseline Predictor Variables Used in Multivariable Models**

Variable	30-day All-Cause Readmission		1-Year All-Cause Readmission	
	Hazard Ratio (95% CI)	p-value	Hazard Ratio (95% CI)	p-value
Age (per year)	1.03 (1.00 - 1.06)	0.084	1.01 (0.99 - 1.03)	0.246
Female	0.71 (0.16 - 1.26)	0.221	0.85 (0.56 - 1.14)	0.278
Pre-existing Frailty	1.23 (0.94 - 1.52)	0.155	1.23 (1.06 - 1.40)	0.015
LVEF > 50% *	1.17 (0.47 - 1.87)	0.659	1.08 (0.76 - 1.04)	0.632
Pre-existing Peripheral Vascular Disease	1.27 (0.85 - 1.69)	0.259	1.10 (0.92 - 1.28)	0.329
Pre-existing Cerebrovascular Disease	1.21 (0.83 - 1.59)	0.326	1.01 (0.82 - 1.20)	0.957
Pre-existing Chronic Obstructive Pulmonary Disease	1.16 (0.72 - 1.60)	0.513	1.48 (1.19 - 1.77)	0.007
Creatinine < 120 µmol/L †	1.37 (0.81 - 1.93)	0.274	0.76 (0.44 - 1.08)	0.099
Heart Failure Hospitalization within 90 days	1.80 (1.48 - 2.12)	0.000	1.18 (0.88 - 1.48)	0.286
Year of Transcatheter Aortic Valve Replacement (per year) ‡	0.90 (0.75 - 0.05)	0.168	0.95 (0.89 - 1.01)	0.108
Post-procedural Warfarin Use	-	-	1.30 (1.00 - 1.60)	0.089

CI: confidence interval

\* reference LVEF ≤ 50%, † reference creatinine ≥120 µmol/L ‡ reference year 2007

## Supplemental References:

1. Tu JV, Chu A, Donovan LR, Ko DT, Booth GL, Tu K, Maclagan LC, Guo H, Austin PC, Hogg W, Kapral MK, Wijesundera HC, Atzema CL, Gershon AS, Alter DA, Lee DS, Jackevicius CA, Bhatia RS, Udell JA, Rezai MR, Stukel TA. The cardiovascular health in ambulatory care research team (canheart): Using big data to measure and improve cardiovascular health and healthcare services. *Circ Cardiovasc Qual Outcomes*. 2015;8:204-212.
2. Lee DS, Stitt A, Wang X, Yu JS, Gurevich Y, Kingsbury KJ, Austin PC, Tu JV. Administrative hospitalization database validation of cardiac procedure codes. *Med Care*. 2013;51:e22-26.
3. Wald R, Quinn RR, Luo J, Li P, Scales DC, Mamdani MM, Ray JG, University of Toronto Acute Kidney Injury Research G. Chronic dialysis and death among survivors of acute kidney injury requiring dialysis. *JAMA*. 2009;302:1179-1185.
4. Ko DT, Yun L, Wijesundera HC, Jackevicius CA, Rao SV, Austin PC, Marquis JF, Tu JV. Incidence, predictors, and prognostic implications of hospitalization for late bleeding after percutaneous coronary intervention for patients older than 65 years. *Circ Cardiovasc Interv*. 2010;3:140-147.