Circulation

ORIGINAL RESEARCH ARTICLE

Temporal Trends and Clinical Consequences of Wait Times for Transcatheter Aortic Valve Replacement

A Population-Based Study

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BACKGROUND: Transcatheter aortic valve replacement (TAVR) represents a paradigm shift in the therapeutic options for patients with severe aortic stenosis. However, rapid and exponential growth in TAVR demand may overwhelm capacity, translating to inadequate access and prolonged wait times. Our objective was to evaluate temporal trends in TAVR wait times and the associated clinical consequences.

METHODS: In this population-based study in Ontario, Canada, we identified all TAVR referrals from April 1, 2010, to March 31, 2016. The primary outcome was the median total wait time from referral to procedure. Piecewise regression analyses were performed to assess temporal trends in TAVR wait times, before and after provincial reimbursement in September 2012. Clinical outcomes included all-cause death and heart failure hospitalizations while on the wait list.

RESULTS: The study cohort included 4461 referrals, of which 50% led to a TAVR, 39% were off-listed for other reasons, and 11% remained on the wait list at the conclusion of the study. For patients who underwent a TAVR, the estimated median wait time in the postreimbursement period stabilized at 80 days and has remained unchanged. The cumulative probability of wait-list mortality and heart failure hospitalization at 80 days was ≈2% and 12%, respectively, with a relatively constant increase in events with increased wait times.

CONCLUSIONS: Postreimbursement wait time has remained unchanged for patients undergoing a TAVR procedure, suggesting the increase in capacity has kept pace with the increase in demand. The current wait time of almost 3 months is associated with important morbidity and mortality, suggesting a need for greater capacity and access.

Key Words: transcatheter aortic valve replacement ■ TAVR

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Clinical Perspective

What Is New?

- There is a lack of data to inform the limits of an acceptable TAVR wait time.
- We studied the trends in TAVR wait times, from initial referral to procedure date.
- We found that in the postreimbursement period, for patients who underwent a TAVR, the median wait time has remained unchanged, suggesting increased capacity has kept pace with increasing demand.
- However, this wait time period is associated with excessive mortality and morbidity, suggesting current wait times are not appropriate.

What Are the Clinical Implications?

- Our study demonstrates that prolong TAVR wait times are associated with adverse outcomes including mortality and readmission.
- As such, wait times for TAVR should emerge as a key quality indicator.
- Our study highlights the need for mechanisms to monitor and report wait times, as well as wait time adverse events, in real time.
- There is a need for research to inform how best to triage TAVR patients on the wait list, as well as to develop benchmarks for the maximum acceptable wait times for TAVR patients of different risk categories.

Transcatheter aortic valve replacement (TAVR) is the preferred less invasive therapeutic option for inoperable and high risk patients with severe aortic stenosis,[1,2] with emerging evidence suggesting it is a reasonable alternative for intermediate risk patients.[3,4] TAVR represents a paradigm shift in the therapeutic options for aortic stenosis. Since the first-in-man case in 2002,[5] and subsequent regulatory approval,[6–8] there has been rapid adoption with >100 000 implantations performed annually in >40 countries.[9]

The rapid and exponential growth in demand for TAVR has the potential to overwhelm current capacity, which in turn will translate to prolonged wait times. Indeed, 2 previous studies during the early experience with TAVR suggested ≈10% and 14% of patients die on the TAVR wait list.[10,11] Previous work from our group estimated the hypothetical impact of increasing wait time on the effectiveness of TAVR[12] using a mathematical simulation model utilizing data from the seminal randomized clinical trials in this area. We found that TAVR wait time beyond 60 days would negate any potential benefit of TAVR over traditional surgical aortic valve replacement (SAVR).[12] These studies have raised the concern of whether current TAVR infrastructure has sufficient capacity to meet this growing demand. As such, wait time for TAVR has emerged as a key quality indicator for TAVR.[13]

Despite this, there is a lack of data to inform the limits of an acceptable TAVR wait time. Accordingly, our objective was to address this gap in knowledge through evaluation of the temporal trends in TAVR wait time and its association with rehospitalization for heart failure (HF) and mortality, using a population-level registry of all TAVR procedures in Ontario, Canada, from April 2010 to March 2016.

METHODS

This retrospective cohort study was approved by the Institutional Research Ethics Board at Sunnybrook Health Sciences Center, at the University of Toronto, Ontario, Canada, prior to data collation and analysis. The use of anonymized administrative data without patient consent at the Institute for Clinical Evaluative Sciences is allowed in Ontario, based on provincial privacy legislation. We adhered to the STROBE statement (Strengthening the Reporting of Observational Studies in Epidemiology) for reporting of observational studies. Analytic methods and study materials will be available to other researchers for purposes of reproducing results or replicating the procedure; however, individual data will not be available, to be compliant with privacy regulations in Ontario, Canada. Please contact Dr Wijeysundera, who is responsible for maintaining availability of analytic methods and study materials.

Context

Ontario is the largest province in Canada, with a population of 13.6 million. All residents have universal access to health care and hospital services through a publicly-funded healthcare program administered by a single third-party payer, the Ontario Ministry of Health and Long Term Care. TAVR has been available in Ontario since 2007, despite only obtaining regulatory approval by Health Canada in 2011. Approval for the preregulatory implantation of TAVR prosthesis was obtained by a federal Special Access Program. Across Canada, postmarket access and reimbursement decisions are made at the provincial level; in Ontario, reimbursement and funding were approved for TAVR in September 2012.

Data Sources

Our study utilized data collected in the CorHealth Ontario TAVR Registry. The TAVR CorHealth Registry contains demographic, comorbidity, and procedural variables from the 10 hospitals across the province. These data elements have been validated through selected chart abstractions and core laboratory analyses.

Data from the TAVR CorHealth Registry were linked using encrypted unique patient identifiers to population-based administrative databases housed at the Institute for Clinical Evaluative Sciences in Toronto, Ontario. We used the Canadian Institute for Health Information Discharge Abstract Database for data on acute hospitalizations, as well as to supplement baseline comorbidity and procedural data. Dementia diagnoses were determined through

linkage with any of the following 3 administrative databases: the Ontario Health Insurance Program physician claims database, the Ontario Drug Benefit database, or the Canadian Institute for Health Information Discharge Abstract Database. Validated databases derived from the Institute for Clinical Evaluative Sciences were used to identify diabetes,[14,15] HF,[16,17] hypertension,[18] and chronic obstructive pulmonary disease.[19] Medical frailty was determined using the John Hopkins Adjusted Clinical Group (ACG) case-mix adjustment system (The Johns Hopkins ACG System, version 10).[20] Mortality was ascertained via the Registered Persons Database, as were additional demographic variables such as neighborhood income quintile and rural residence.

Patient Selection

We included all TAVR referrals in Ontario from April 1, 2010, to March 31, 2016. Each episode of care, represented the length of time a patient remained on the TAVR wait list defined by a start date (referral date) and removal date (off-listing or procedure date). As such, unique patients could contribute 2 or more separate episodes of care to the overall cohort of referrals by being on the wait list on separate occasions. We excluded episodes with data quality issues (ie, patients with a death date died before the referral date) or with an invalid off-listing or procedure date.

The episodes of care were categorized into 3 subcohorts based on wait-list outcome. First, the *TAVR subcohort* included all episodes that resulted in a TAVR procedure. The *off-list subcohort* included only episodes that resulted in off-listing for another reason, (off-list reasons were classified into 6 categories: medical treatment only, not TAVR candidate because of medical decision, not TAVR candidate because of patient decision, death on the wait list, rereferral for SAVR, or clinical follow-up). Finally, the *wait list subcohort* included patients who were still alive on the wait list at the conclusion of the study observation period (ie, a decision regarding TAVR eligibility had not yet been confirmed, or a decision to off-list for other reasons had not yet been reached).

Outcome Variables

Patients were followed from the date of referral until March 31, 2016. Our primary outcome of interest was median total wait time from referral date to either TAVR date or off-list date. Temporal trends were assessed quarterly. We evaluated important time intervals, specifically the time from referral to the date of the decision by the Heart Team (*wait time 1*) and the time from date of decision by the Heart Team to the date of the procedure (*wait time 2*). In addition, we evaluated the first consultation wait time, the interval from referral to the date of critical TAVR workup diagnostic tests (eg, coronary angiogram, echocardiogram, computer tomography) and the interval from the last diagnostic test to the TAVR acceptance date.

Our two primary clinical outcomes of interest were death and the incidence of HF-related hospitalizations while on the wait list. HF was determined based on the most responsible diagnosis on the Canadian Institute for Health Information Discharge Abstract Database hospitalization record.

Statistical Analysis

For the baseline characteristics, we compared patients in the 3 subcohorts using one-way ANOVA for continuous variables and the Chi-squared (χ^2) test for categorical variables.

Piecewise regression analyses were performed to assess temporal trends in wait times in response to an empirical inflection point corresponding to the implementation of provincial TAVR reimbursement in September 2012 (referred to as the intervention). The dependent variable was the median wait time per quarter, measured in days. Three parameters were tested in the piecewise regression model: β_1, the measure of the slope of the median total wait time prior to the intervention; β_2, a measure of the change immediately after the intervention to test whether the intervention had an immediate effect on median total wait time (ie, testing for a "step" function); and β_3, a measure of the change in the slope from pre- to postintervention to determine whether the rate of change in the median total wait time changed after the intervention (Table I in the online-only Data Supplement for full description). Residuals were plotted over time and the Durbin–Watson statistic was used to determine if first-order autocorrelation was present. If autocorrelation was present, the autoregressive parameters were included in the final piecewise regression model for correction.

To identify potential drivers of short versus long wait times for TAVR, we built a Cox regression model, with the dependent variable being the time to TAVR. We forced all baseline characteristics into the model. In terms of interpretation, variables with a hazard ratio (HR) > 1 were associated with a shorter TAVR wait time, while those with a HR < 1 were associated with a longer TAVR wait time.

For the outcome analysis, we constructed cumulative incidence function (CIF) curves to describe the probability of wait-time mortality or HF-related hospitalization in the presence of competing risks (an event which precludes the occurrence of the primary event of interest). Patients were followed from date of TAVR referral to time of death/hospitalization or censoring at the end of the follow-up period (March 31, 2016). The competing risk that we considered included the following: death (for the HF analysis); a TAVR procedure; and any reason for off-list from the wait list (for example referral to SAVR etc.). To identify predictors of either mortality or HF hospitalizations while on the wait list, we build Fine–Gray competing risks models, again accounting for the competing risks above, while adjusting for all patient-level baseline characteristics.

All data analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina). Statistical significance was considered to be two-sided *P* values of <0.05.

RESULTS

A total of 4535 TAVR referrals were recorded between April 1, 2010, and March 31, 2016. As seen in Figure 1, after applying exclusions for data quality (n=74), this consisted of 2231 (50%) referrals that led to a TAVR procedure, including 14 patients having more than one procedure. There were 1757 (39%) referrals who were off-listed. Off-list reasons were as follows: medi-

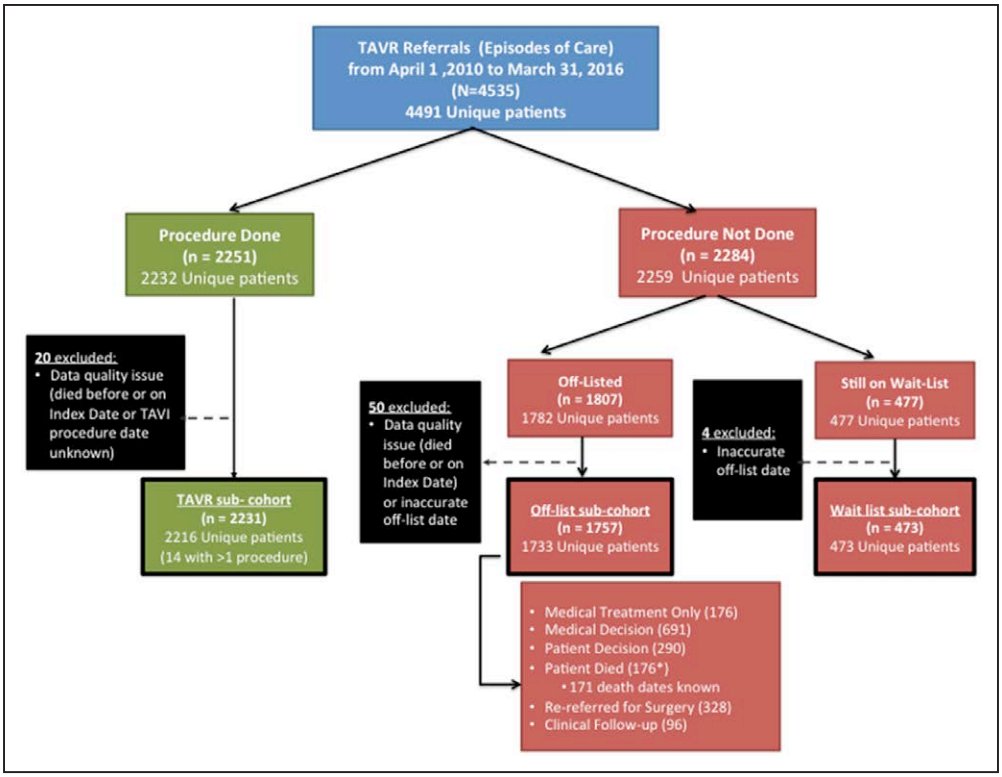

Figure 1. Selection of patient cohort.
*5 patients with missing death dates. TAVI indicates transcatheter aortic valve implantation; and TAVR, transcatheter aortic valve replacement.

cal treatment (n=176), non-TAVR candidate due to a medical decision (n=691), non-TAVR candidate due to patient decision (n=290), wait-list death (n=176), rereferral for SAVR (n=328), and clinical follow-up (n=96). The remaining 473 (11%) TAVR referrals represented censored patients who were still on the wait list at the end of the study period (Figure 1). As seen in Figure I in the online-only Data Supplement, referrals and procedural rates increased substantially throughout the study period, from less than 10 per quarter to a maximum of 441 and 202 per quarter, respectively.

Baseline Characteristics

The mean age of our total cohort was 81.5 years, with 46% females (Table 1). Patients in the TAVR subcohort had a significantly higher prevalence of coronary artery disease, previous coronary artery bypass surgery (CABG), SAVR, and percutaneous coronary intervention (PCI), while comorbidities such as frailty and dementia were significantly higher in patients who were in the off-list subcohort (P<0.001). In the TAVR subcohort, the procedures were elective in 82% with the majority (79%) via femoral access (Table 1).

Wait-Time Analysis

The mean and median total wait times for the combined TAVR and off-list subcohorts were 111 and 79 days, respectively (Table 2). A substantial proportion of patients had at least some of their diagnostic work-up completed prior to their initial referral. In patients who had diagnostic tests postreferral, the longest wait time was for having a CT scan (median 46 days).

In the TAVR subcohort (Table 3), the median total wait time from referral to procedure day was 105 days. The median wait time from referral to acceptance (wait time 1) was 54 days while the median wait time from acceptance to procedure (wait time 2) was 34 days. Wait-time analysis for the off-list and wait-list subcohorts are described in Tables II and III in the online-only Data Supplement, respectively. In the off-list subcohort, the median total wait time from referral to off-list was 54 days. In the wait-list subcohort, 111 (23.5%) patients had been accepted for TAVR. The median time from referral to acceptance (wait time 1) in this subgroup was 70 days (Table III in the online-only Data Supplement).

Quarterly median wait times and estimates generated by the piecewise regression analyses for the overall and subcohorts are shown in Figure 2A through 2C and Table I in the online-only Data Supplement. There was a significant difference between the total wait-time trends in the pre- and postprovincial TAVR funding periods (Figure 2A; P<0.001); this was significant in the TAVR subcohort (Figure 2B; P<0.001) and of borderline significance in the off-list subcohort (Figure 2C; P=0.065). There was a significant downward

Table 1. Baseline Characteristics

Characteristic	Total Cohort (n=4461)	TAVR Subcohort (n=2231)	Off-List Subcohort (n=1757)	Wait-List Subcohort (n=473)	*P* Value
Demographic					
Age, y (mean±SD)	81.5±8.0	81.8±7.6	81.4±8.6	81.1±7.7	0.160
Female sex (N, %)	2051 (46.0%)	1008 (45.2%)	802 (45.6%)	241 (51.0%)	<0.001
Rural resident (N, %)	532 (11.9%)	261 (11.7%)	218 (12.4%)	53 (11.2%)	0.004
Income Quintile					
1 (lowest)	775 (17.4%)	349 (15.6%)	327 (18.6%)	99 (20.9%)	0.001
2	913 (20.5%)	463 (20.8%)	355 (20.2%)	95 (20.1%)	
3	870 (19.5%)	457 (20.5%)	323 (18.9%)	90 (19.0%)	
4	938 (21.0%)	459 (20.6%)	384 (21.9%)	95 (20.1%)	
5 (highest)	899 (20.2%)	451 (20.2%)	355 (20.2%)	93 (19.7%)	
Medical Comorbidities (N, %)					
Prior MI	620 (13.9%)	295 (13.2%)	269 (15.3%)	56 (11.8%)	<0.001
Prior HF	2626 (58.9%)	1333 (59.7%)	1030 (58.6%)	263 (55.6%)	<0.001
Prior ICD	<=5*	22 (1.0%)	24 (1.4%)	<=5*	<0.001
Prior PPM	263 (5.9%)	115 (5.2%)	117 (6.7%)	31 (6.6%)	<0.001
Prior CABG	713 (16.0%)	505 (22.6%)	168 (9.6%)	40 (8.5%)	<0.001
Prior PCI	642 (14.4%)	375 (16.8%)	209 (11.9%)	58 (12.3%)	<0.001
Prior stroke	269 (6.0%)	115 (5.2%)	127 (7.2%)	27 (5.7%)	<0.001
Atrial fibrillation	931 (20.9%)	461 (20.7%)	381 (21.7%)	89 (18.8%)	0.001
DM	1714 (38.4%)	883 (39.6%)	650 (37.0%)	181 (38.3%)	0.003
HTN	3837 (86.0%)	1965 (88.1%)	1480 (84.2%)	392 (82.9%)	<0.001
HLD	2518 (56.4%)	1310 (58.7%)	929 (52.9%)	279 (59.0%)	<0.001
PVD	282 (6.3%)	119 (5.3%)	122 (6.9%)	41 (8.7%)	<0.001
CAD	1709 (38.3%)	937 (42.0%)	625 (35.6%)	147 (31.1%)	<0.001
COPD	1533 (34.4%)	749 (33.6%)	628 (35.7%)	156 (33.0%)	<0.001
Prior malignancy	274 (6.1%)	126 (5.7%)	114 (6.5%)	34 (7.2%)	<0.001
Dementia	353 (7.9%)	140 (6.3%)	169 (9.6%)	44 (9.3%)	<0.001
Frailty†	825 (18.5%)	349 (15.6%)	385 (21.9%)	91 (19.2%)	<0.001
Prior Valve Surgery					
Aortic	265 (5.9%)	162 (7.3%)	81 (4.6%)	22 (4.7%)	0.003
Mitral	82 (1.8%)	47 (2.1%)	24 (1.4%)	11 (2.3%)	0.002
Tricuspid	<=5*	17 (0.8%)	10 (0.6%)	<=5*	<0.001
Status of Procedure					
Urgent	N/A	181 (8.1%)	N/A	N/A	
Elective	N/A	1836 (82.3%)	N/A	N/A	
TAVR Access Site					
Transfemoral	N/A	1766 (79.2%)	N/A	N/A	
Nontransfemoral	N/A	356 (15.9%)	N/A	N/A	

N=referrals. CABG indicates coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; HF, heart failure; HLD, hyperlipidemia; HTN, hypertension; ICD, implantable cardioverter defibrillator; MI, myocardial infraction; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; PPM, permanent pacemaker; SD, standard deviation; and TAVR, transcatheter aortic valve replacement.

*All data that presented had less than 3.5% missing data, excluding the missing data for status of procedure (9.6%) and for access site (4.9%).

†Frailty was determined using the John Hopkins Adjusted Clinical Group Case-Mix adjustment system (The Johns Hopkins ACG System, version 10).

trend in the median total wait time by quarter during the period prior to the implementation of the provincial TAVR funding program (2010Q4 to 2012Q1) in both subcohorts (*P*<0.001 for TAVR subcohort (Figure 2B) and *P*=0.003 for off-list subcohort (Figure 2C and Table I in the online-only Data Supplement). The estimated

Table 2. Wait-Time Intervals in the TAVR and Off-List Subcohorts Combined (n=3988)

Variable	N	Mean	SD	Median	Lower–Upper Quartile
Wait time to first consult	2583	30	43	20	3–44
Wait time to coronary angiogram	1969 (60%)*	52	90.1	27	3–67
Wait time to echocardiogram	2447 (62%)†	63	95.4	37	12–71
Wait time to computed tomography scan	2330 (80%)‡	63	80.4	46	19–78
Total wait time; referral to either procedure or off-list	3983§	111	113.7	79	36–151

SD indicates standard deviation; and TAVR, transcatheter aortic valve replacement.
*1338 (40%) = Coronary angiogram performed before TAVR referral.
†1499 (38%) = Echo performed before TAVR referral.
‡581 (20%) = Computed tomography performed before TAVR referral.
§Death date missing for 5 patients.

median wait time in this prefunding era decreased by 63%, from 322 to 118 days in TAVR subcohort, and by 51%, from 220 to 108 days, in the off-list subcohort.

In contrast, the median total wait time did not decline substantially by quarter in the postfunding period (2012Q3 to 2015Q4) for the TAVR subcohort, and instead stabilized at 82 to 84 days (Figure 2B). In the off-list subcohort, there was a continued, but attenuated, decrease in median wait time from 90 to 32 days (Figure 2C). The piecewise regression estimates of median wait time 1 and wait time 2 for the TAVR subcohort are seen in Figures IIA and IIB in the online-only Data Supplement, respectively, showing similar trends as the TAVR total wait-time analysis.

In Table IV in the online-only Data Supplement, we show the results of our modeling to identify drivers of total wait time for patients undergoing TAVR. We found that high risk features such as needing an urgent in-hospital TAVR, a valve-in-valve procedure in patients with previous SAVR, previous HF or coronary artery disease, and older age were associated with shorter wait times for TAVR (HR>1). In contrast, comorbidities such as frailty and chronic obstructive pulmonary disease were associated with a longer wait time (HR<1). Nonetheless, there were inconsistencies, in that dementia appeared to be associated with shorter wait times. Moreover, counterintuitively, patients with a rural residence had a shorter wait time.

Clinical Outcomes

Over the entire study period, the cumulative probability of mortality and HF hospitalization on the wait list was 4.3 and 14.7%, respectively. At the median time of ≈80 days (the stabilized wait-time point) the cumulative probability of mortality was 2%, while that for HF hospitalization was 12% (Figures 3A and 3B). The median time to death was 63 days. With decreasing wait times, there was diminished mortality and HF hospitalization. However, as seen in Figures 3A and 3B, there was a relatively constant increase in the probability of death or hospitalization with increasing wait times, with no threshold below which event rates were flat. The strongest predictor of either wait-time mortality or rehospi-

Table 3. TAVR Subcohort (n=2231) Wait-Time Intervals

Variable	N	Mean	SD	Median	Lower–Upper Quartile
Wait time to first consult	1551	30	44.4	18	1–42
Wait time to coronary angiogram	1265 (61%)*	54	90.4	28	5–69
Wait time to echocardiogram	1468 (66%)†	63	95.8	35	11–70
Wait time to computed tomography scan	1636 (84%)‡	63	75.6	45	19–78
Wait time from the last test to acceptance	1625	28	42.1	12	1–38
Wait time 1; referral to acceptance	2231	79	95.0	54	15–112
Wait time 2; acceptance to procedure	2231	52	55.8	34	13–73
Total wait time; referral to procedure	2231	131	116.8	105	53–174

SD indicates standard deviation; and TAVR, transcatheter aortic valve replacement.
*804 (39%) = Coronary angiogram performed before TAVR referral.
†740 (34%) = Echocardiogram performed before TAVR referral.
‡322 (16%) = Computed tomography scan performed before TAVR referral.

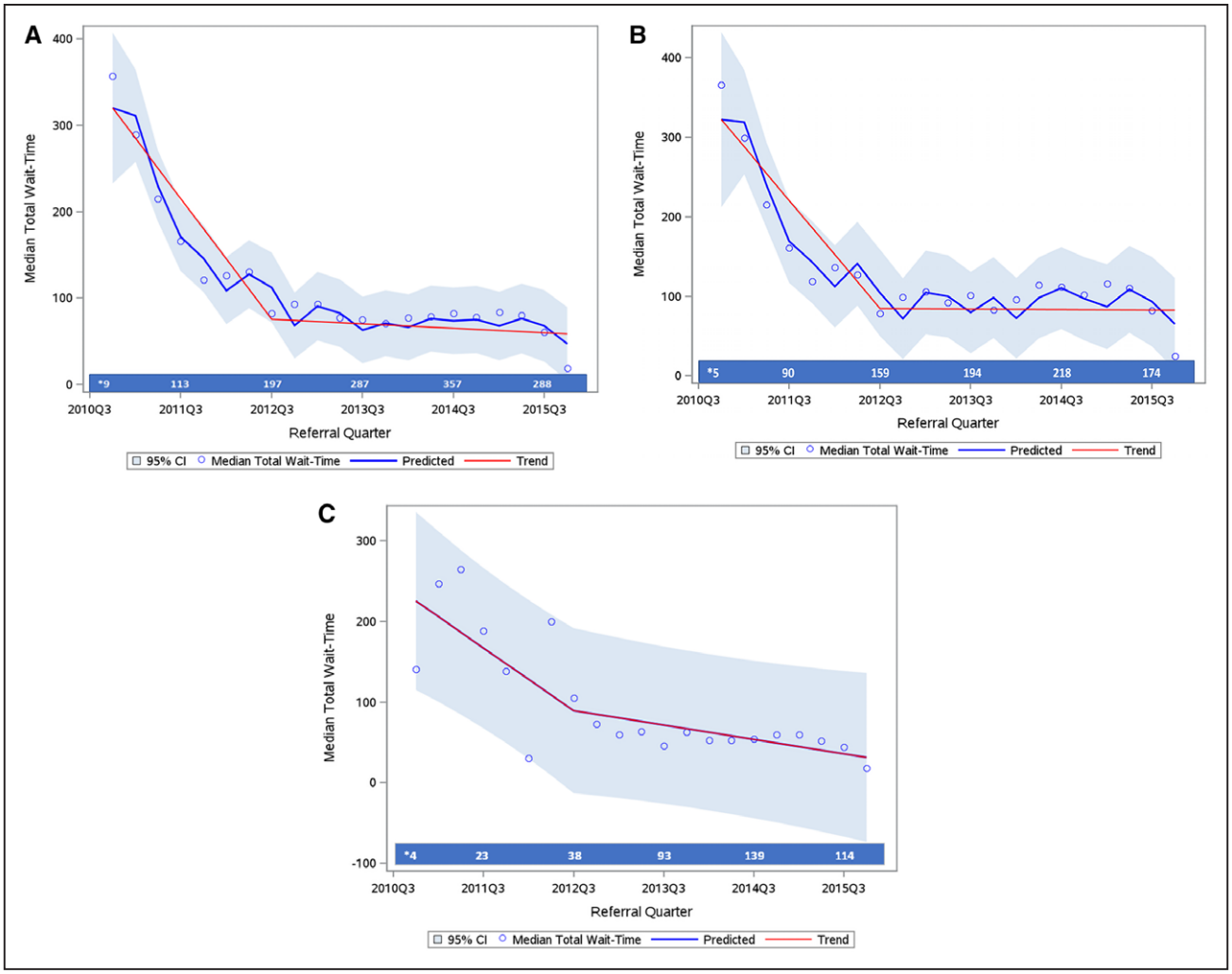

Figure 2. Piecewise linear regression models.
A, Combined TAVR and off-list subcohorts quarterly median total wait time; from referral to either procedure or off-list. **B**, TAVR subcohort quarterly total wait time; from referral to procedure. **C**, Off-list subcohort quarterly median total wait time; from referral to off-list. *Absolute number of patients waiting in each quarter. CI indicates confidence interval; and TAVR, transcatheter aortic valve replacement.

talization was older age and prior comorbidities, such as HF (Tables V and VI in the online-only Data Supplement, respectively).

DISCUSSION

In this population-based retrospective cohort study of all TAVR referrals in Ontario, we found that despite an increase in TAVR referrals, as well as procedures, over the last 4 years, total wait time for the procedure has remained constant at ≈80 days. This suggests that funding and capacity has kept pace with demand. In contrast, the time from referral to off-listing has continued to decrease. In the most recent period (2015 Q4), the time from referral to off-list is estimated at only 1 month, suggesting that TAVR heart teams have improved the efficiency of their processes for appropriate case selection. The total estimated wait time to the TAVR procedure of almost 3 months (≈80 days) in the postfunding era is associated with important clinical consequences, with 2% cumulative probability of mortality and 12% cumulative probability of a HF hospitalization. Importantly, there was no threshold period below which wait times were clearly safe; clinical events and wait times had a relatively constant relationship, with lower mortality and morbidity associated with less time on the wait list.

The presence or absence of symptoms is a key element in decision-making for the timing of aortic valve replacement. Although there may be a prolonged latent asymptomatic period with good prognosis, once symptoms develop, prognosis is extremely poor, with a 2-year mortality rate of 50% if left untreated.[21,22] There is robust evidence that aortic-valve replacement prolongs life in patients with symptomatic severe aortic stenosis, regardless of the type or severity of symptoms.[21,23–25] Considering its dismal prognosis, symptomatic patients with severe aortic stenosis should be referred promptly,

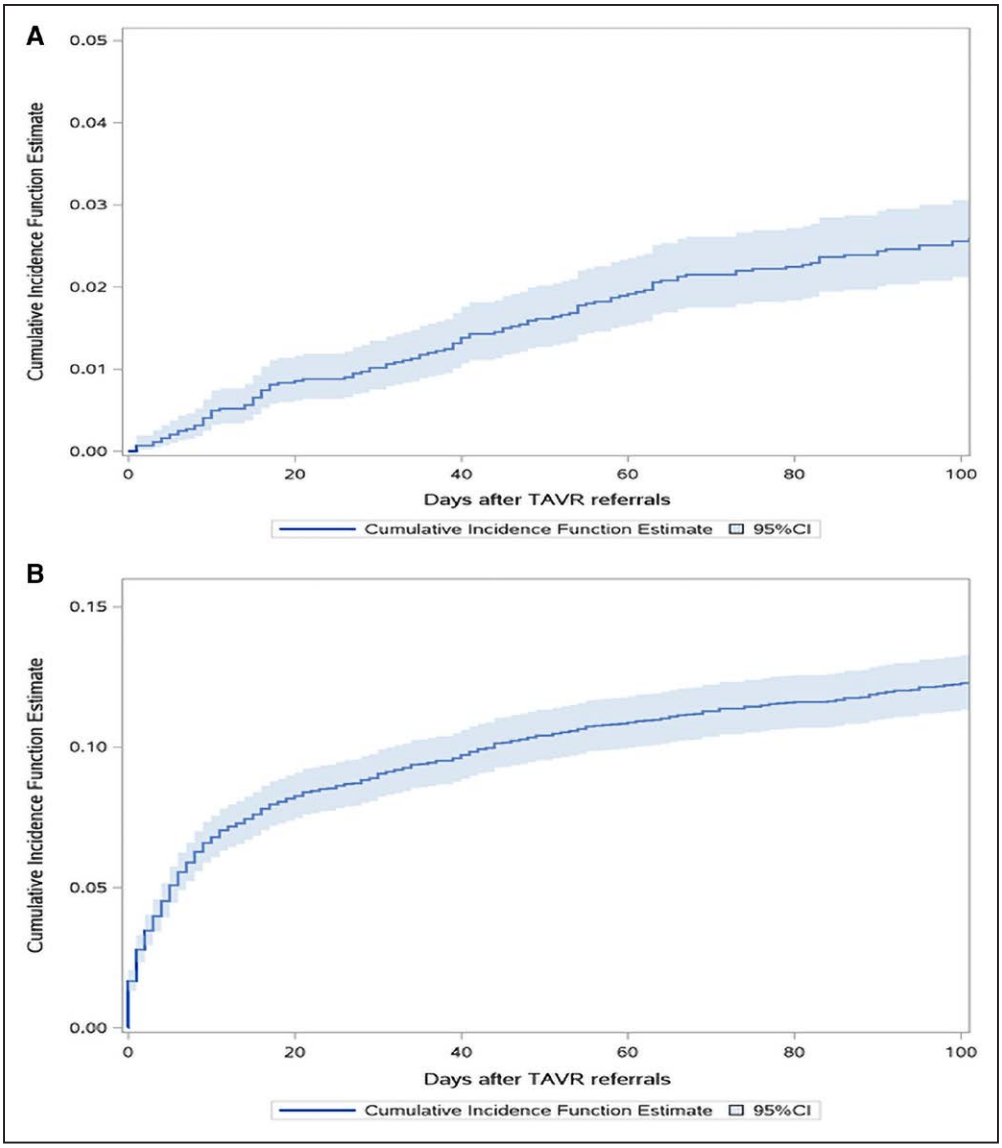

Figure 3. Cumulative incidence functions.
A, Mortality on wait list in the first 100 days. **B**, Heart failure hospitalization on wait list in the first 100 days. CI indicates confidence interval; and TAVR, transcatheter aortic valve replacement.

and require timely aortic valve replacement, reinforcing the need for wait-time management.[26]

Wait-time management has been of increasing importance in Canada and other jurisdictions.[27] Indeed, the majority of OECD (Organisation for Economic Co-operation and Development) countries monitor national waiting time statistics and have procedural waiting time benchmarks, across multiple areas of medicine.[28] The Canadian Wait Time Alliance has produced wait-time benchmarks for SAVR of 42 and 14 days for elective and urgent cases, respectively, based on an expert consensus process.[29] However, the area of wait times has a number of inherent difficulties, the first of which is how the wait-time metric is measured. In the literature, there are different ways that are used to measure wait time for cardiovascular interventions. In Ontario, *wait time* is defined as the interval from the referral to a cardiovascular surgeon to the date of surgery.[30] However, other studies define wait time as the shorter interval between the acceptance decision for cardiovascular intervention and the intervention date.[31] It is important to consider the entire waiting interval, measured from first contact with medical care provider to procedure date, given the patient is at risk throughout this period, and there are processes within this time period that can be potentially improved and streamlined.[32]

Total wait time reflects the balance between demand in one hand, and the availability of resources and capacity on the other. There is extremely limited published literature on TAVR wait times. To our knowledge, the only previous paper was of 358 patients from 3 centers; it found a median wait time of 71 days.[11]

This was broadly similar to our findings. We found that in the postfunding period there was a continued decrease in wait time from 90 to 32 days in the off-list subcohort, while the total wait time did not change in the TAVR subcohort, instead stabilizing around 80 days (going from 84 to 82 days from the beginning to the end of the postfunding era). The stabilization of wait time subintervals in the TAVR subcohort was also observed during the postfunding era, specifically the time from referral to acceptance (wait time 1) and from acceptance to procedure (wait time 2). We hypothesize that wait time has remained essentially unchanged for patients undergoing a TAVR procedure because the increase in capacity has kept pace with the increase in demand. This increase in capacity encompasses both the diagnostic phase (wait time 1) and procedural phase (wait time 2). In contrast, the decrease in the time for off-listing non-TAVR candidates, suggests ongoing efficiencies in the preprocedural diagnostic phase in determining appropriate TAVR candidates.

Although reassuring that wait times have not deteriorated over the study period, with the expansion of TAVR into intermediate and lower risk patients as recommended by clinical practice guidelines in 2017,[33] the subsequent dramatic increase in demand will likely overcome capacity. Interestingly, when evaluating clinical features that are associated with short versus long wait times. We found, in general, that high risk features were associated with a shorter time to TAVR, while additional comorbidities, such as lung disease and frailty, were associated with delays. However, there was inconsistency, in that dementia was associated with shorter wait time, as was having a rural residence. This suggests that there may not be a systematic approach to triaging cases, reinforcing the need for wait-time management.

The critical question is whether this wait time for TAVR patients is appropriate. To date, there is no consensus on what is an acceptable wait time for TAVR. In comparison, TAVR wait times are almost 2-fold higher than the upper limit for the Canadian elective SAVR wait-time benchmarks. However, these were consensus-based SAVR benchmarks and not linked to clinical outcomes. As a conceptual framework, we would argue that the acceptability of a prolonged wait time should be based on the adverse clinical consequences of the delay. We reported a 4.3 and 14.7% cumulative probability of wait list mortality and HF hospitalization, respectively, over the entire study period and importantly, the shape of the cumulative incidence function curves showed a relatively constant increase in risk over time on the wait list. These suggest that the current wait time for patients undergoing TAVR, although stable, remains excessive. To place this mortality in context, previous contemporary registries and trials in TAVR show a 30-day all-cause mortality of 3.9 and 3.4%, while that for SAVR is 4.1 and 6.5% for intermediate and high risk patients, respectively.[2,3,34] The latest randomized SURTAVI trial (Surgical Replacement and Transcatheter Aortic Valve Implantation) demonstrated even lower 30-day all-cause mortality: 2.2% for TAVR and 1.7% for SAVR.[34] Rationally, one can argue that the mortality during the wait time for a procedure postdiagnosis should be less than that after the procedure itself. Furthermore, HF hospitalization is associated with important morbidity and healthcare costs. TAVR patients who require hospitalization before their TAVR require a prolonged post-TAVR stay, which also is associated with increased costs.[35,36]

What should the ideal TAVR wait time be? Our study was not designed to answer this question, and our exploratory analyses on the predictors of wait-time mortality and rehospitalization were likely underpowered. However, we can offer a few insights. There is a need to be able to triage patients based on their risk for adverse events on the wait list. This is an area of ongoing research by our group, building on this initial work by extending our dataset to include other provinces across Canada, with the goal of being adequately powered to identify drivers of wait times and wait-time adverse events, and to develop prediction models to triage patients into low, medium, and high risk. Wait-time benchmarks should reflect the risk profile and be informed by empirical evidence. There are multiple methods, such as discrete event modeling, that permit a more informed approach to queue management.[37,38]

Our study must be interpreted in the context of several limitations. First, we did not include changes in quality of life or symptoms on the wait list, as these data elements are not included in the CorHealth Ontario registry. As patients remain on the wait list, particularly if they are hospitalized, it is likely that there will be a concomitant reduction in quality of life and substantial impact on post-TAVR recovery. It is increasingly recognized that a positive outcome for TAVR must include an improvement in quality of life.[38] A critical determinant of post-TAVR improvements in quality of life is the preprocedural status; as such deteriorations, due to hospitalizations, are likely to have a substantial impact on post-TAVR recovery. Second, we were not able to assess the consequences of prolonged wait time on post-TAVR procedural outcomes and how this should influence decisions about wait-time management. This is an area of ongoing research. Finally, ours was observational study with multiple confounders that we are not able to account for. As such, our conclusions should be considered hypothesis-generating, and not conclusive.

CONCLUSION

Despite an improvement since the availability of provincial funding, the wait time from referral to TAVR has remained essentially unchanged for patients undergoing

TAVR. The current wait time of almost 3 months until procedure is associated with important morbidity and mortality. This highlights the importance of wait-time management in TAVR as an area of focus for further research and quality improvement.

ARTICLE INFORMATION

Received December 25, 2017; accepted February 27, 2018.

Guest Editor for this article was Stephan Windecker, MD.

The online-only Data Supplement is available with this article at https://www.ahajournals.org/journal/circ/doi/suppl/10.1161/circulationaha.117.033432.

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Acknowledgments

The authors acknowledge that the clinical registry data used in this publication is from participating hospitals through CorHealth Ontario, which serves as an advisory body to the Ontario Ministry of Health and Long-Term Care, is funded by the Ontario Ministry of Health and Long-Term Care, and is dedicated to improving the quality, efficiency, access and equity in the delivery of the continuum of adult cardiac, vascular and stroke services in Ontario, Canada.

Sources of Funding

This study is funded by a Grant-in-Aid from the Heart and Stroke Foundation of Canada and from an Early Research Award from the Ministry of Research and Innovation of Ontario. This study was supported by the Institute for Clinical Evaluative Science, which is funded by an annual grant from the Ontario Ministry of Health and Long-Term Care. The opinions, results and conclusions reported in this paper are those of the authors and are independent from the funding sources. No endorsement by the Institute for Clinical Evaluative Science or the Ontario Ministry of Health and Long-Term Care is intended or should be inferred. Parts of this material are based on data and/or information compiled and provided by Canadian Institute for Health Information; however, the analyses, conclusions, opinions, and statements expressed in the material are those of the authors, and not necessarily those of Canadian Institute for Health Information. Dr Wijeysundera is supported by a Distinguished Clinical Scientist Award from the Heart and Stroke Foundation of Canada. Dr Ko is supported by a midcareer personnel award from the Heart and Stroke Foundation, Ontario Provincial Office (Canada).

Disclosures

Dr Wijeysundera receives research funding from Medtronic Inc. and Edwards Life Sciences. The other authors report no conflicts of interest.

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