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Annual Outcomes With Transcatheter Valve Therapy

From the STS/ACC TVT Registry

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ABSTRACT

BACKGROUND The Society of Thoracic Surgeons (STS)/American College of Cardiology (ACC) Transcatheter Valve Therapy (TVT) Registry has been a joint initiative of the STS and the ACC in concert with multiple stakeholders. The TVT Registry has important information regarding patient selection, delivery of care, science, education, and research in the field of structural valvular heart disease.

OBJECTIVES This report provides an overview on current U.S. TVT practice and trends. The emphasis is on demographics, in-hospital procedural characteristics, and outcomes of patients having transcatheter aortic valve replacement (TAVR) performed at 348 U.S. centers.

METHODS The TVT Registry captured 26,414 TAVR procedures as of December 31, 2014. Temporal trends between 2012 and 2013 versus 2014 were compared.

RESULTS Comparison of the 2 time periods reveals that TAVR patients remain elderly (mean age 82 years), with multiple comorbidities, reflected by a high mean STS predicted risk of mortality (STS PROM) for surgical valve replacement (8.34%), were highly symptomatic (New York Heart Association functional class III/IV in 82.5%), frail (slow 5-m walk test in 81.6%), and have poor self-reported health status (median baseline Kansas City Cardiomyopathy Questionnaire score of 39.1). Procedure performance is changing, with an increased use of moderate sedation (from 1.6% to 5.1%) and increase in femoral access using percutaneous techniques (66.8% in 2014). Vascular complication rates are decreasing (from 5.6% to 4.2%), whereas site-reported stroke rates remain stable at 2.2%.

CONCLUSIONS The TVT Registry provides important information on characteristics and outcomes of TAVR in contemporary U.S. clinical practice. It can be used to identify trends in practice and opportunities for quality improvement. (J Am Coll Cardiol 2015;■:■–■) © 2015 by the American College of Cardiology Foundation and The Society of Thoracic Surgeons.

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ABBREVIATIONS AND ACRONYMS

ACC = American College of Cardiology

KCCQ = Kansas City Cardiomyopathy Questionnaire

STS = Society of Thoracic Surgeons

STS PROM = Society of Thoracic Surgeons Predicted Risk of Mortality

TAVR = transcatheter aortic valve replacement

TVT = transcatheter valve therapy

VARC = Valve Academic Research Consortium

The Society of Thoracic Surgeons (STS) and the American College of Cardiology (ACC) developed the STS/ACC Transcatheter Valve Therapy (TVT) Registry in concert with multiple stakeholders, including regulatory agencies and industry (1-4). Originally designed to satisfy the Center for Medicare & Medicaid Services (CMS) National Coverage Determination (NCD) requirements for coverage with evidence development, TVT captures data on patient characteristics, procedural variables, and outcomes, including quality of life. Among other requirements, key provisions are that the heart team and hospital are participating in a prospective, national, audited registry that: 1) consecutively enrolls patients; 2) accepts all manufactured devices; and 3) follows the patient for at least 1 year. Implementation of the registry satisfies these requirements. The completeness of the datasets is designed to document specific answers to clinical and device questions required by the coverage with evidence developments, and the data are sufficiently detailed to allow robust retrospective analyses of deidentified data for quality assessment and performance improvement purposes, including: 1) generation of important descriptive information regarding evolving trends in overall patient selection, device use, and outcomes; 2) the development of validated risk prediction models; 3) the ability to provide individual patient risk prediction; and 4) benchmarking of site and provider-level outcomes on the basis of patient risk. These functions serve as the basis for informing patient and provider decisions regarding the appropriateness of available therapeutic strategies using outcome-driven data. Additional benefits include the ability to prospectively pose specific clinical research questions that can be used to query selective deidentified datasets within the registry. Monitoring of temporal trends in existing retrospective deidentified data from this (and other similar well-designed and conducted) registries, regarding real-world patient selection, procedural outcomes, and adverse events, may also prove to have important pre- and post-market regulatory implications relative to device label expansion and surveillance.

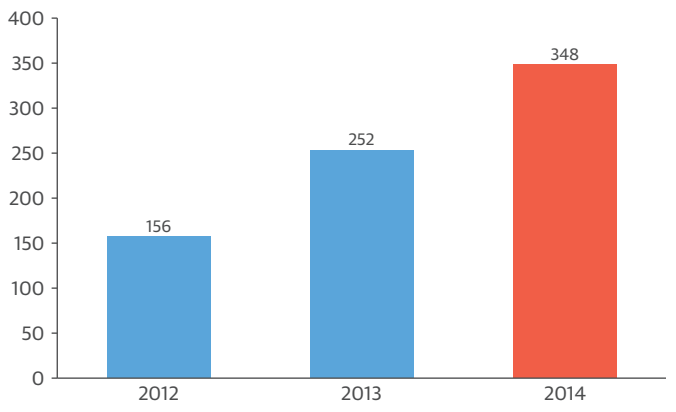
This report provides an update on the information obtained from this joint initiative, provides a baseline benchmark report for the performance of transcatheter aortic valve replacement (TAVR) in the United States, and informs development of global registries (5,6). It also facilitates identification of specific items of interest, which can then be selected for more focused statistical assessment to better understand inference and/or causal relationships (7-9).

Since inception of the TVT Registry in December 2011 and implementation of the CMS NCD, TAVR technology has been dispersed, with 348 centers performing TAVR in 48 of 50 states (**Figure 1**) in 2014. It has been the platform for 4 Food and Drug Administration (FDA) post-approval studies for SAPIEN (Edwards Lifesciences, Irvine, California), CoreValve (Medtronic, Inc., Minneapolis, Minnesota), and MitraClip devices (Abbott Vascular, Temecula, California).

In the process of implementation, a data dictionary was developed using standardized definitions (10,11) and was subsequently refined to include 308 elements, including baseline patient characteristics, outcomes, procedural performance, and device selection.

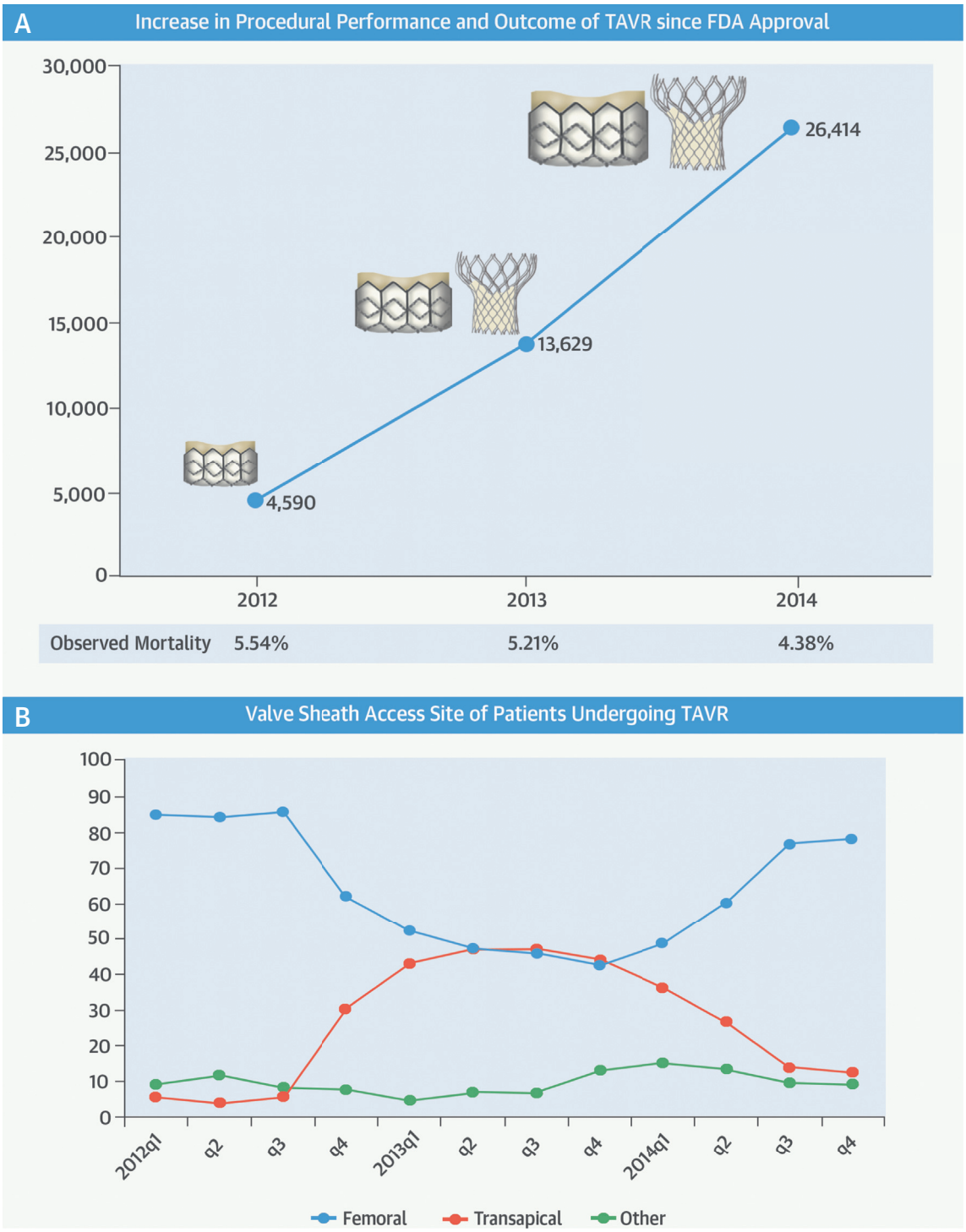
The registry captures patient-reported health status (Kansas City Cardiomyopathy Questionnaire [KCCQ]) not previously collected by a national registry (12,13), which includes social and quality-of-life indicators. It also assesses disability, neurocognitive function, and effect on social/recreational activities in patients who experience a stroke. In addition, discharge location documents the need for extended or nursing home care. Finally, a Unique Device Identifier field has been added to allow tracking of specific unique devices, pending implementation of a Unique Device Identifier strategy by the FDA.

FIGURE 1 Sites Enrolled in the TVT Registry, 2012 to 2014



As part of regulatory approval, the Centers for Medicare & Medicaid Services published a National Coverage Determination that described optimal characteristics of sites to be involved in transcatheter aortic valve replacement (TAVR), as well as required enrollment of all consecutive TAVR patients as a requirement for reimbursement. This resulted in the rapid growth of U.S. centers (**Central Illustration**). TVT = transcatheter valve therapy.

CENTRAL ILLUSTRATION **Cumulative TAVR Procedures and Valve Sheath Access Sites of Patients Submitted to the TVT Registry, 2012 to 2014**



(A) Since the Food and Drug Administration (FDA) approval of transcatheter aortic valve replacement (TAVR) in 2011, there has been marked increase in procedural volume, the result of enhanced recognition of the problem of severe aortic stenosis in elderly higher-risk patients and technological improvements making the devices and procedure safer. **(B)** The changing valve sheath access site strategy is the result of multiple factors, including the FDA instructions for use, the presence or absence of peripheral arterial disease, and changing technology. TVT = transcatheter valve therapy.

Although the initial TVT Registry was limited to the SAPIEN device and its initial specific indication for approval (i.e., transfemoral access for high-risk or inoperable native aortic stenosis), new modules have been added to allow for alternative access, new iterations of FDA-approved TAVR valves from various manufacturers, and the application of TAVR for treatment of degenerated surgical biological valves. Finally, the TVT Registry has been expanded to include elements specific for MitraClip and other transcatheter mitral devices.

TABLE 1 Patient Demographics and Baseline Characteristics of Patients Undergoing TAVR

	2012-2014 (n = 26,378)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Demographics				
Sex				<0.0001
Male	50.5	48.8	52.3	
Female	49.5	51.2	47.8	
Age, yrs				<0.0001
Mean	82	82	81	
Median	84	84	83	
Race				
White	93.8	94.2	93.5	0.0155
Black	3.8	3.7	4.0	0.2807
Cardiac history				
Permanent pacemaker	16.8	17.0	16.5	0.2996
Prior ICD	4.3	4.2	4.5	0.3789
Prior PCI	35.6	35.5	35.7	0.7176
Prior CABG	31.4	32.2	30.5	0.0031
Prior cardiac surgeries (open heart)	32.5	33.0	32.0	0.0589
1 previous surgery	27.8	28.0	27.7	
2 previous surgeries	4.0	4.3	3.7	
Prior bioprosthetic aortic valve	2.2	1.9	2.6	<0.0001
Prior aortic valve balloon valvuloplasty	13.8	14.8	12.7	<0.0001
Prior mitral, tricuspid, or pulmonic valve procedure	2.7	2.8	2.6	0.4716
Other history				
Prior stroke	12.3	12.5	12.1	0.3620
Transient ischemic attack	8.9	8.9	9.0	0.9388
Prior carotid endarterectomy or stent	7.6	6.9	8.3	<0.0001
Peripheral arterial disease	31.7	32.2	31.0	0.0375
Current/recent smoker	5.3	5.2	5.3	0.7698
Hypertension	89.0	88.7	89.2	0.2534
Diabetes mellitus	37.0	36.4	37.9	0.0087
Currently on dialysis	4.2	4.3	4.0	0.1532
Creatinine >2.0 mg/dl (excludes dialysis)	5.7	5.9	5.6	0.3723
Home oxygen	13.3	13.9	12.6	0.0008
Hostile chest	8.5	9.0	7.8	0.0006
Pre-procedural status				
Prior MI	25.3	25.2	25.4	0.6436
MI within 30 days prior to procedure	2.2	2.1	2.4	0.0992
Heart failure within past 2 weeks	76.7	75.1	78.4	<0.0001
Cardiac procedure within past 30 days	8.9	9.5	8.3	0.0004
Porcelain aorta	7.0	7.2	6.8	0.1666
Atrial fibrillation (prior history)	40.8	40.1	41.6	0.0200
5-m walk test performed	61.1	58.8	75.2	<0.0001
Normal (<6 s)	18.4	17.0	19.4	0.0002
Slow (≥6 s)	81.6	83.0	80.6	

Values are % unless otherwise indicated.

CABG = coronary artery bypass graft; ICD = implantable cardioverter-defibrillator; MI = myocardial infarction; PCI = percutaneous coronary intervention; TAVR = transcatheter aortic valve replacement.

STATISTICAL METHODS

Baseline patient characteristics and in-hospital outcomes were summarized by percentages and compared across subgroups using chi-square, Wilcoxon, or Kruskal-Wallis 2-sided tests, as appropriate. For all analyses, p values <0.05 were considered statistically significant, and all analyses were performed at the Duke Clinical Research Institute using SAS software (version 9.3, SAS Institute, Cary, North Carolina).

CURRENT EXPERIENCE. This initial report profiles in-hospital characteristics and outcomes of TAVR. Initial detailed outcomes of MitraClip will be reported separately. Subsequent updates will also include longer-term outcomes on both TAVR and any approved transcatheter mitral valve therapies.

RESULTS

SITES AND PROCEDURES. At 348 centers, as of December 2014, there were 26,414 TAVR patient records (Figure 1, Central Illustration). Data are currently captured for all commercial TAVR devices including SAPIEN, SAPIEN XT, and CoreValve. Approximately 10,000 additional TAVR procedures are not currently captured in the TVT Registry because they were performed as part of investigational device exemption trials; regulatory concerns currently preclude inclusion of investigational devices in TVT Registry reports.

For this first update, data are divided into 2 major groups: 1) patients with TAVR procedures between January 1, 2012, and December 31, 2013; and 2) patients with TAVR procedures between January 1, 2014, and December 31, 2014.

PATIENT CHARACTERISTICS. Overall, 50.5% of patients with TAVR procedures from 2012 to 2014 were male, with a mean age of 82 years; 91% were ≥70 years of age, whereas 68% were ≥80 year of age (Table 1, Figure 2). Less than 5% of all patients were black. Multiple comorbidities were common, including prior revascularization (either percutaneous coronary intervention or coronary artery bypass graft), prior stroke, diabetes, and peripheral arterial disease. Other high-risk characteristics

include moderate or severe chronic lung disease (Online Figure 1) and prior myocardial infarction (**Table 1**). Approximately 83% of patients were in New York Heart Association functional class III/IV (Online Figure 2). Concordant with this, approximately 82% had evidence of frailty, with a slow 5-m walk test (**Table 1**). The KCCQ provided a further estimate of abnormal self-reported health status. Although only obtained in approximately 76% of patients, the mean KCCQ score was 41, with a statistically significant, but clinically insignificant increase over time (p for trend <0.0001). This indicates poor health status, including reduced function and quality of life (**Figure 3**). Finally, a history of or current atrial fibrillation was identified in approximately 41% of patients.

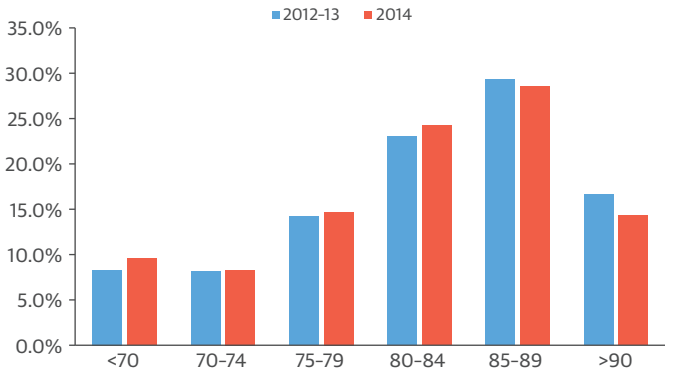
The changes in baseline characteristics over the 2 timeframes were clinically minor, although statistically significant due to the size of the registry. Overall, the mean STS risk score (14) was 8.34%, with a decrease in the median STS risk score from 2012 to 2014 (**Figure 4A**) (p for trend <0.0001). This is probably related in part to the expansion of TAVR to high-risk patients, from its initial restriction to inoperable or prohibitive-risk patients. The absolute breakdown of STS risk scores can be seen in **Figure 4B**, showing some decline in the highest-risk patients (STS risk score ≥15).

CARDIAC ASSESSMENT. Hemodynamic assessment data is shown in **Table 2**. By protocol, all patients had to have severe native aortic stenosis determined by the heart team to be eligible for treatment. The etiology of the aortic stenosis was degenerative due to tricuspid disease in most patients (91.7%). In the remainder, the etiology either was bicuspid or could not be confidently distinguished, usually because of excessive calcification and leaflet fusion. The majority of patients had no, trace/trivial, or only mild aortic regurgitation; only 20% had moderate or severe regurgitation. Assessment of pre-procedural aortic annulus size varied among sites; transesophageal echocardiography use for this specific purpose has decreased, whereas the use of computed tomography angiography has increased (p for trend <0.0001) (Online Figure 3).

More than 90% of patients had severe native aortic stenosis as the primary indication. A small number of patients (2.2%) were treated with the off-label indication of valve-in-valve for degenerated biologic prostheses. As per the CMS NCD, 2 surgeons were required to evaluate each patient for suitability for TAVR. This process was documented in 94.8% of patients. The initial categories (**Figure 5**) included extreme and high risk but continue to evolve as the procedure is performed in intermediate- and even lower-risk patients.

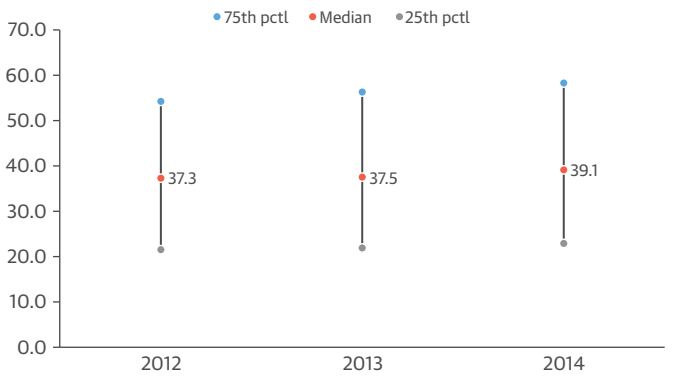
Diagnostic angiography identified that 37% of patients had no significant coronary lesions or had patent grafts to vascular beds that had been previously found to have significant stenoses. The distribution of significant coronary artery disease in the remaining patients ranged between the 2 groups, but most commonly involved 1 or 3 major epicardial vessels. Severe left ventricular dysfunction (ejection fraction <30%) was documented in approximately 7.4% of patients by assessment of left ventricular

FIGURE 2 Age of Patients Undergoing TAVR, 2012 to 2014



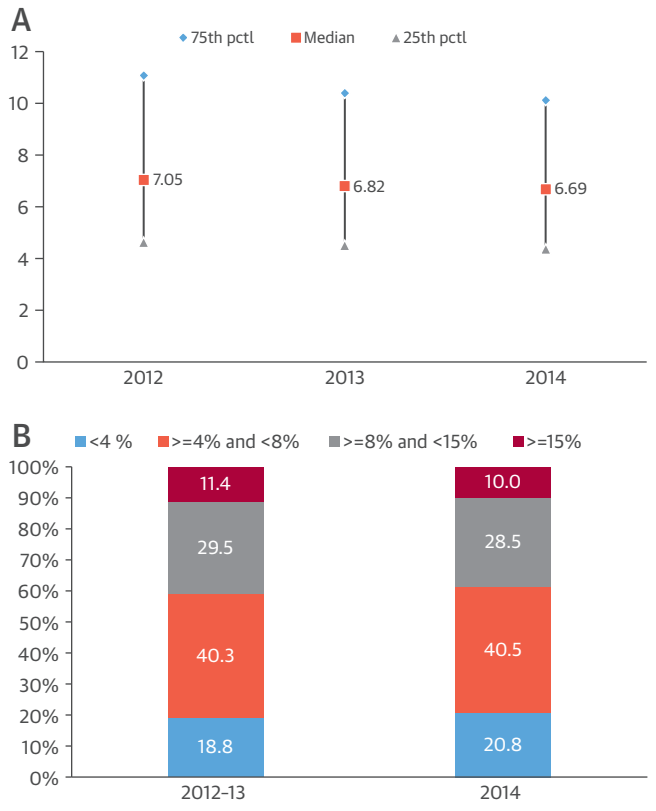
The majority of patients from 2012 to 2013 and 2014 are from 80 to 90 years of age. Although there were significant differences over time, these differences were not clinically significant. TAVR = transcatheter aortic valve replacement.

FIGURE 3 pre-TAVR Health Status (KCCQ)—Overall Summary Score at Baseline



Kansas City Cardiomyopathy Questionnaire (KCCQ) data were only obtained in approximately 76% of patients. Given the size of the sample, the results indicated that the patients have poor health status. TAVR = transcatheter aortic valve replacement.

FIGURE 4 STS Risk Score (SAVR) of Patients Undergoing TAVR



(A) Percentiles. **(B)** Distribution of Society of Thoracic Surgeons (STS) risk scores for surgical aortic valve replacement (SAVR) (%) of patients undergoing transcatheter aortic valve replacement (TAVR). Two surgeons calculate the STS Predicted Risk of Mortality (PROM) score as part of the TAVR screening process. The expansion of the TAVR instructions for use to include lower-risk patients has resulted in a decline in STS scores.

function, assessed by either catheterization or echocardiography.

PROCEDURAL PERFORMANCE. Greater than 90% of cases were performed electively (Table 3); the remainder were usually classified as urgent. During the 2 time periods analyzed, the procedure itself was typically performed in a hybrid operating room suite (Online Figure 4); only 10% to 13% were performed in a catheterization laboratory. This may change as the technology improves with decreasing catheter sizes and may shift the procedure in the future to more frequent performance in a catheterization laboratory.

The specific mode of anesthesia (Online Figure 5) was typically general, with moderate sedation used in <5%, although with a clinically and statistically meaningful increase in use over time (p for trend <0.0001). This has changed with smaller TAVR catheters, so that the use of moderate sedation has become increasingly frequent in selected centers (15). This trend can be expected to increase because it can result in a shorter length of hospital stay and should result in improved patient preference and tolerance of the procedure. Performance of cardiopulmonary bypass was infrequent (<5%) and usually performed emergently as the result of a complication.

Access site has changed substantially (**Central Illustration**) (p for trend <0.0001), which is the result of several factors, including the initial FDA indications for use (i.e., transfemoral vs. alternative access), the presence or absence of peripheral arterial disease (which may preclude a femoral approach), or the specific devices available. It is anticipated that this will continue to change. Another important benchmark is the sheath access method (Online Figure 6), with variability characterized by increasing use of a percutaneous approach.

VALVE PERFORMANCE. Approximately 95% of TAVR valves had a mean pressure gradient <20 mm Hg post-implantation (Table 4). The degree of site-reported post-TAVR aortic regurgitation was typically none or trace/trivial, with a statistical but not clinically substantial change over time (p for trend <0.0001) (Figure 6). However, these results were not assessed by a core laboratory and may represent difficulty in accurate site-reported assessment and/or under-reporting. This has implications for longer follow-up, as increasing degrees of residual aortic regurgitation are associated with worse long-term outcome. Post-TAVR aortic regurgitation was often assessed by echocardiography, although angiography was used in some institutions. The degree of regurgitation may change over time with changing new technology, as well as more optimal prosthetic valve sizing on the basis of computed tomography measurements.

PROCEDURAL OUTCOME. The success rate with device implantation in the correct anatomic position has been excellent, and most recently was 97.4% (Table 4). Using Valve Academic Research Consortium (VARC)-1 criteria, device success was 92.7%, reflecting that the device was in the correct anatomic position, as well as satisfactory intended performance of the valve (10,11,16).

In the most recent experience, about one-third of all patients had a hospital complication. However, procedure-related cardiac complications were uncommon at <2% (Table 5). The most common intraprocedural cardiac complication was the need for a new pacemaker (Figure 7), which occurred in

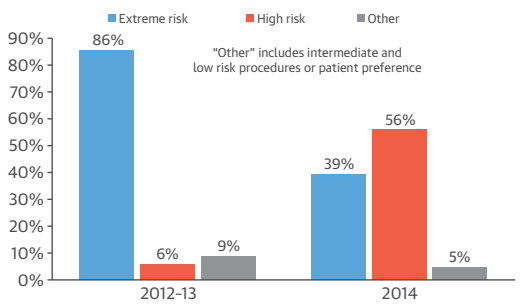
approximately 10% of patients overall, but has increased over time (p for trend <0.0001). This is most likely the result of expanding the types of prostheses implanted to include CoreValve, which has been associated with a higher incidence of conduction system abnormalities (17-20). New onset of atrial fibrillation was seen in approximately 7%. Life-threatening intraprocedural complications, such as annular dissection, aortic rupture, or perforation with tamponade, were uncommon. Device migration or embolization was rare.

Noncardiac complications predominated (**Figures 8 and 9**). Vascular complications were the most common, were typically related to access-site or arterial bleeding, and resulted in the frequent need for blood transfusions (Online Figure 7). There was a decrease in VARC bleeding (p for trend <0.0001) and vascular complications (p for trend <0.0001) over time. These may continue to decrease as the technology matures, with smaller access sheaths and catheters and improved approaches using vascular access closure devices. That will be an important metric to follow because vascular complications have been associated with increased morbidity/mortality. A new requirement for dialysis was infrequent (1.8%), as was the development of acute kidney injury (2.5%).

Neurological events in association with TAVR have received considerable attention. The TVT Registry has a unique protocol in place that provides centralized clinical adjudication for site-reported neurological events according to VARC definitions. The frequency of clinically adjudicated stroke was low, at approximately 2%.

Discharge status and length of stay can be seen in Online Figures 8 and 9. The mean post-procedure

FIGURE 5 Heart Team Reason for TAVR



The heart team is mandated to evaluate all patients undergoing transcatheter aortic valve replacement (TAVR). The reason for the indication for TAVR, in terms of patient risk, continues to evolve.

TABLE 2 Hemodynamic Assessment (pre-TAVR)

	2012-2014 (n = 26,414)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Coronary artery disease				
Number of diseased vessels				0.0158
None	36.9	37.6	36.2	
1	19.6	19.7	19.6	
2	16.1	15.7	16.5	
3	27.4	27.0	27.8	
Left main stenosis ≥50%	10.8	11.0	10.6	0.3239
Ejection fraction				
Severe dysfunction (<30%)	7.4	7.0	7.8	0.0141
Aortic regurgitation				<0.0001
None/trace	41.3	40.0	42.4	
Mild	38.5	38.5	38.4	
Moderate/severe	20.4	21.5	19.2	
Valve morphology				<0.0001
Bicuspid	1.9	1.6	2.3	
Tricuspid	91.7	92.5	90.9	
Mitral regurgitation				0.0013
None, trace, or mild	70.4	69.5	71.3	
Moderate or severe	29.6	30.5	28.7	
Tricuspid regurgitation				0.8160
None, trace, or mild	76.0	75.9	76.0	
Moderate or severe	24.0	24.1	24.0	

Values are %.
TAVR = transcatheter aortic valve replacement.

TABLE 3 Procedural Evaluation and Performance of Patients Undergoing TAVR

	2012-2014 (n = 26,414)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Evaluation by 2 cardiac surgeons	94.8	93.5	96.1	<0.0001
Procedure status				<0.0001
Elective	90.5	89.5	91.5	
Urgent	9.3	10.3	8.4	
Emergency	0.2	0.2	0.1	
Salvage	0.0	0.0	0.0	
Procedure aborted	2.1	2.9	1.3	<0.0001
Conversion to open heart surgery	1.4	1.4	1.3	0.4507
Reason converted				0.4067
Valve dislodged to aorta	2.9	3.2	2.5	
Valve dislodged to left ventricle	22.3	21.2	23.6	
Ventricular rupture	18.9	15.3	23.0	
Annulus rupture	12.3	12.2	12.4	
Aortic dissection	8.9	8.5	9.3	
Coronary occlusion	6.6	6.9	6.2	
Other	28.3	32.8	23.0	
Mechanical assist device in place at start of procedure (any)	1.1	1.4	0.8	<0.0001
Cardiopulmonary bypass	3.5	4.1	2.9	<0.0001
Elective	27.9	28.7	26.6	
Emergent	72.1	71.3	73.4	

Values are %.
TAVR = transcatheter aortic valve replacement.

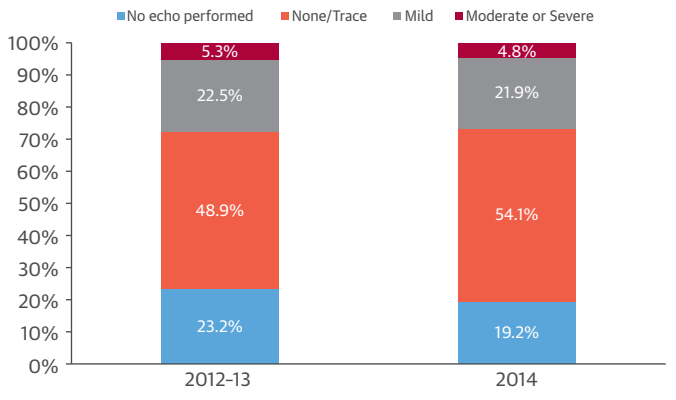
TABLE 4 Post-Procedure TAVR Valve Performance

	2012-2014 (n = 26,414)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Device performance				
Device implanted successfully	97.3	97.0	97.4	0.3252
Device success–VARC-1 criteria (18)	92.7	91.7	93.7	<0.0001
Final aortic valve mean gradient				
Normal (<20 mm Hg)	94.6	93.5	95.5	<0.0001
Mild (20–40 mm Hg)	4.0	4.9	3.2	
Moderate/severe (>40 mm Hg)	1.4	1.6	1.3	

Values are %.
TAVR = transcatheter aortic valve replacement; VARC = Valve Academic Research Consortium.

length of stay continues to shorten (Online Figure 9) (p for trend <0.0001), with the most recent 2014 data documenting a mean length of stay of 6.2 days. As previously stated, the use of more moderate sedation, more transfemoral access, vascular closure devices for true percutaneous entry, and potentially, the shift to a catheterization laboratory environment with recovery in a cardiac care unit (rather than a surgical intensive care unit) can be expected to further decrease length of stay, making the procedure more cost-efficient. An important finding is that two-thirds of patients were able to be dismissed home, and another one-fourth were dismissed to a temporary extended-care facility, despite these patients having a mean age of 82 years and with approximately 80% having New York Heart Association functional class III/IV symptoms pre-TAVR.

FIGURE 6 Aortic Regurgitation at Discharge (%) Post-TAVR



The small, but significant, changes in site-read aortic regurgitation post-transcatheter aortic valve replacement (TAVR) may have important implications.
Echo = echocardiography.

Overall unadjusted in-hospital mortality (Figure 10) throughout this time period was <5%. The primary cause of mortality was cardiac, and was not substantially different over the period of observation (Table 6).

OBSERVATIONS. These benchmark data from the TVT Registry have multiple important messages:

1. TAVR candidates have advanced age and multiple comorbidities, which either make them at high risk for surgical aortic valve replacement or render them inoperable.
2. The patients are highly symptomatic, with symptoms that are often refractory.
3. There has been little clinically significant change in patient demographics since the inception of the TVT Registry. However, it does draw attention to the change in initial indications for TAVR, which included patients at very high risk for surgery or inoperable. This is highlighted by the mean STS PROM (Predicted Risk of Mortality) score of 8.16% in 2014 and 8.34% for all 3 years, which are quite different than the recommendation in the guidelines (21). It is possible that some unusual characteristics that would lead experts to consider a patient surgically inoperable are not included in the current STS PROM risk model. With the CMS mandate, 2 experienced cardiovascular surgeons reviewed the patients independently and rendered the opinion that they were either high-risk or inoperable.
4. The procedure continues to evolve, with clinically and statistically significant changes in procedural access, procedural performance, and need for anesthesia.
5. Mortality, myocardial infarction, kidney injury, and neurological complications are low, and patients appear to be clinically stable despite statistically significant changes.
6. The most common complications are vascular and bleeding requiring transfusion. As technology continues to provide smaller access equipment, these complications should improve.

USES OF THE REGISTRY NOW AND IN THE FUTURE. These results of the earliest TAVR experience in the United States captured by the TVT Registry have provided important scientific information on early outcomes of TAVR compared with other selected clinical experiences and pivotal randomized trials. The TVT Registry data have been used to broaden the indications for use by the FDA (22) and have provided important information on patient subsets that are at particularly high risk of adverse events,

namely, those with significant chronic obstructive pulmonary disease, chronic renal disease, and high STS score (9). Furthermore, linkage of patients enrolled in the TVT Registry with CMS administrative claims data has produced critically-needed insights into longer-term patient follow-up, including rehospitalization and mortality rates in the first year following TAVR (9). Future reports will be able to quantify outcomes over subsequent years, as well as trends in short- and long-term outcomes related to new technologies, changing patient selection criteria, and evolving clinical management strategies, and may facilitate comparative assessment of different devices.

Several important uses of TVT Registry data have occurred or are being planned that will further expand the importance of these updated reports:

1. Development of a TAVR-specific risk prediction algorithm focusing on in-hospital mortality. Future risk prediction algorithms will look at longer-term mortality, stroke, and other nonfatal outcomes.
2. These data will also be used to evaluate the relationship between volume and outcome for TAVR, which has important implications for continued utilization of the approach.
3. TVT Registry data is currently serving as a primary input for FDA-mandated device surveillance. This is under consideration as part of a broader FDA initiative for Medical Device Reporting requirements. At the present time, the TVT Registry functions as a platform for FDA-approved postmarket surveillance studies for new iterations of current and future devices.
4. Quality improvement initiatives have assumed a central role in medical care. Hospital-specific data is sent to each participating institution (Online Figures 10A and 10B) through an online reporting "dashboard" that allows each institution to benchmark its own practice and outcomes to national and other comparable group averages and is helpful in identifying areas for improvement and optimization.
5. Delivery of care societal issues can also be addressed. A particularly noteworthy finding from the TVT Registry is that black patients make up only 5% of the U.S. TAVR population. Whether this represents differential disease prevalence or access issues remains to be studied.

TABLE 5 Cardiovascular and Device Complications (Prior to Discharge) of Patients Undergoing TAVR

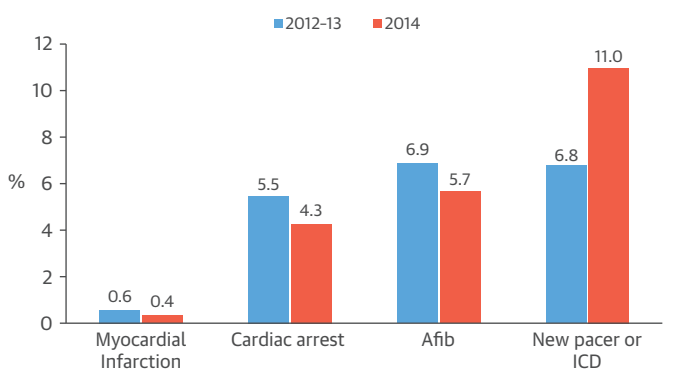
	2012-2014 (n = 26,414)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Cardiac complications				
Cardiac/aortic complications (any)	19.3	18.6	20.2	0.0008
Cardiac complications (procedure-related)	1.9	2.0	1.8	0.2330
Myocardial infarction	0.5	0.6	0.4	0.0316
Coronary compression or obstruction	0.4	0.5	0.4	0.1760
New pacemaker or ICD	8.8	6.8	11.0	<0.0001
New pacemaker*	10.0	7.5	10.5	<0.0001
New ICD*	0.7	0.7	0.7	0.7695
Cardiac arrest	4.9	5.5	4.3	<0.0001
Atrial fibrillation	6.3	6.9	5.7	0.0001
Annular dissection	0.2	0.2	0.2	0.5470
Aortic disruption	0.4	0.4	0.4	0.3449
Perforation with or without tamponade	1.0	1.1	1.0	0.3687
Device complications				
Device complication (any)	2.0	2.1	1.9	0.1567
Device migration	0.3	0.3	0.4	0.5162
Device embolization, left ventricle	0.3	0.4	0.3	0.4399
Device embolization, aorta	0.3	0.3	0.3	0.5154
Device recapture or retrieval	0.4	0.4	0.4	0.9380
Other device-related event	1.0	1.2	0.7	0.4199
Renal complications				
Acute kidney injury, AKIN class stage 3†	2.5	2.7	2.2	0.0076
Dialysis, new requirement	1.8	1.8	1.7	0.3485

Values are %. *New pacer, new ICD captured separately starting in October 2013. †Acute Kidney Injury Network (AKIN) classification

Abbreviations as in Table 1.

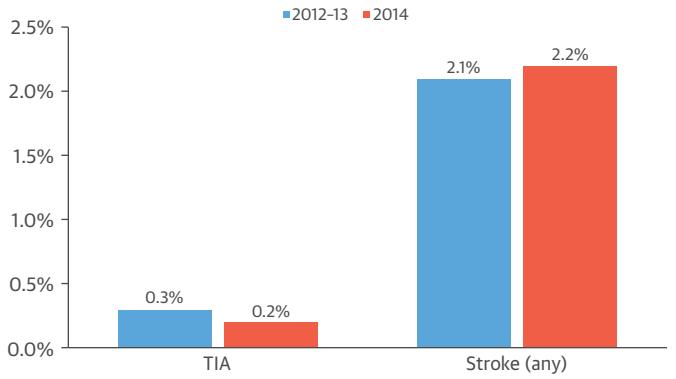
STUDY LIMITATIONS. Registries have both advantages and disadvantages. Although they are not randomized trials, randomized controlled trials can be nested within national registries. In contrast to randomized controlled trials, registries typically include a broader group of patients who are often more heterogeneous than those enrolled in

FIGURE 7 Cardiac Complications of Patients Undergoing TAVR



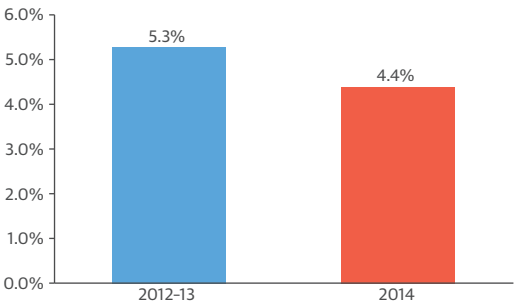
The need for and placement of a new pacemaker or implantable cardioverter-defibrillator (ICD) has probably increased, in part, because of the introduction of new transcatheter aortic valve replacement (TAVR) devices. Afib = atrial fibrillation.

FIGURE 8 Neurological Complications of Patients Undergoing TAVR



Although infrequent, neurological complications following transcatheter aortic valve replacement (TAVR) identify patients at increased risk of subsequent mortality. TIA = transient ischemic attack.

FIGURE 10 In-Hospital Mortality of Patients Undergoing TAVR

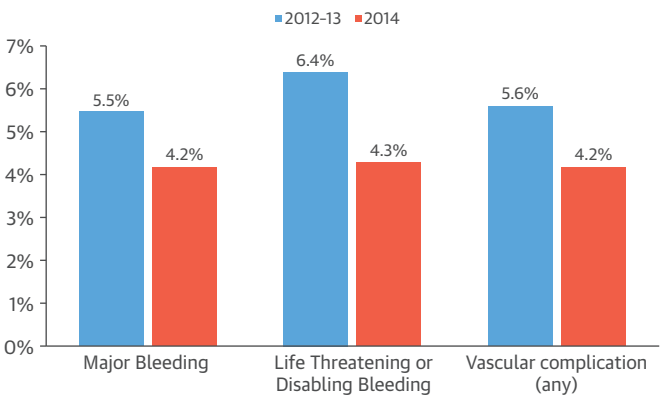


Unadjusted in-hospital mortality in patients undergoing transcatheter aortic valve replacement (TAVR) is decreasing; with improved technology, operator experience, and case selection, this trend can be expected to continue.

pivotal trials. Compliance to specific regimens and recommended treatment standards for both patients and health care teams is difficult to quantify. The issue of confounding but unmeasured variables in patient selection, as well as procedural performance, is extremely important. Statistical assessment is always an "on-treatment analysis." In the TVT Registry, these issues exist along with the absence of core laboratories for image analysis (specifically, the issue of paravalvular leaks), site-reported events, and only partially audited data. Moreover, outcomes are currently unadjusted; thus, comparison of trends over time may be biased by changing patient characteristics and risk profiles.

Finally, these data are limited to commercial TAVR patients. Although discussions have taken place, because of regulatory issues, the inclusion of noncommercial (i.e., cases receiving investigational devices) is not possible until after trials have completed enrollment and have been reported. At that time, patients could be combined retrospectively. These limitations are balanced by the TVT Registry's use of standard definitions, enrollment of virtually all patients undergoing commercial TAVR procedures in the entire United States, and linkage to CMS administrator claims data for longer-term outcomes.

FIGURE 9 Bleeding and Vascular Complications of Patients Undergoing TAVR



Newer technology, with smaller devices and improved vascular access management techniques, has led to a decreasing incidence of both vascular and bleeding complications. TAVR = transcatheter aortic valve replacement.

TABLE 6 In-Hospital Mortality and Cause of Death of Patients Undergoing TAVR

	2012-2014 (n = 26,378)	2012-2013 (n = 13,629)	2014 (n = 12,785)	p Value
Mortality	4.9	5.3	4.4	0.0004
Primary cause of death				0.1863
Cardiac	48.9	49.0	48.7	
Neurological	5.8	5.7	5.8	
Renal	3.1	3.5	2.6	
Vascular	5.5	6.5	4.2	
Infection	4.6	5.4	3.5	
Pulmonary	15.4	13.4	18.1	
Other/unknown	16.8	16.6	17.2	

Values are %.
TAVR = transcatheter aortic valve replacement.

CONCLUSIONS

The TVT Registry was developed and implemented by the ACC and STS during the dispersion of the transformational technology of TAVR. It provides a broad overview of the evolving technology of TAVR and can be used as a benchmark for U.S. TAVR clinical practice patterns and patient outcomes. The TVT Registry is central to a novel approach for post-market surveillance and is the foundation for continuing efforts to provide timely and actionable learning on the basis of scientific evidence throughout the full product life cycle of new emerging technology.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL SKILLS:

Technological advances in device configuration, smaller catheter sizes, and patient-specific access site selection can lower the risk of extracardiac complications in patients undergoing TAVR. Even so, patients undergoing TAVR typically have multiple comorbidities, including advanced age, and the risk of periprocedural stroke remains an important concern.

TRANSLATIONAL OUTLOOK:

Long-term surveillance registries of consecutive patients undergoing TAVR can inform the design of prospective trials to help ensure that innovations in technology and procedural management yield improved clinical outcomes.

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KEY WORDS aortic stenosis, aortic valve replacement, transcatheter aortic valve replacement, valvular heart disease, VARC

APPENDIX For supplemental figures, please see the online version of this article.