The Evolving Management of Aortic Valve Disease: 5-Year Trends in SAVR, TAVR, and Medical Therapy

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Aortic stenosis (AS) and regurgitation (AR) may be treated with surgical aortic valve replacement (SAVR), transcatheter AVR (TAVR), or medical therapy (MT). Data are lacking regarding the usage of SAVR, TAVR, and MT for patients hospitalized with aortic valve disease and the characteristics of the patients and hospitals associated with each therapy. From the Nationwide Readmissions Database, we determined utilization trends for SAVR, TAVR, and MT in patients with aortic valve disease admitted from 2012 to 2016 for valve replacement, heart failure, unstable angina, non−ST-elevation myocardial infarction, or syncope. We also performed multinomial logistic regressions to investigate associations between patient and hospital characteristics and treatment. Among 366,909 patients hospitalized for aortic valve disease, there was a 48.1% annual increase from 2012 through 2016. Overall, 19.9%, 6.7%, and 73.4% of patients received SAVR, TAVR, and MT, respectively. SAVR decreased from 21.9% in 2012 to 18.5% in 2016, whereas TAVR increased from 2.6% to 12.5%, and MT decreased from 75.5% to 69.0%. Older age, female sex, greater severity of illness, more admission diagnoses, not-for-profit hospitals, large hospitals, and urban teaching hospitals were associated with greater use of TAVR. In multivariable analysis, likelihood of TAVR relative to SAVR increased 4.57-fold (95% confidence interval 4.21 to 4.97). TAVR has increased at the expense of both SAVR and MT, a novel finding. However, this increase in TAVR was distributed inequitably, with certain patients more likely to receive TAVR certain hospitals more likely to provide TAVR. With the expected expansion of indications, inequitable access to TAVR must be addressed. **(Am J Cardiol 2019;124:763−771)**

Aortic stenosis (AS) and aortic regurgitation (AR) may be treated with one of 3 strategies: surgical aortic valve replacement (SAVR), transcatheter aortic valve replacement (TAVR), or medical therapy (MT). The United States (US) Food and Drug Administration (FDA) approved TAVR for the treatment of severe AS in inoperable patients[1] in November 2011, high-risk patients[2,3] in October 2012, and intermediate-risk[4,5] patients in August 2016. Small numbers of TAVR procedures may performed off-label for patients with severe AR[6] or mixed AS and AR.[7] However, definitive data are lacking regarding the actual usage of SAVR, TAVR, and MT for patients hospitalized with aortic valve disease and the characteristics of the patients and hospitals associated with each of these therapies. Previous studies demonstrate an increase in the number of SAVR and TAVR procedures performed in the US over time. Medicare data for patients over age 65 show an increase in hospitalizations for SAVR from 24,568 in 1989 to 31,380 in 2011,[8] and TAVR procedure volumes increased from 4,627 procedures at 198 centers in 2012 to 24,808 procedures at 418 centers in 2015.[9] The relative usage of SAVR and TAVR is also evolving. In the Society of Thoracic Surgeons database, the absolute number of TAVR procedures surpassed SAVR procedures in 2016,[10] but the overall rate of SAVR has remained relatively stable.[11] Little is known about trends in patients receiving MT. To address these gaps in knowledge, we sought to characterize temporal trends in the use of SAVR, TAVR, or MT following admission to US hospitals with a primary or secondary diagnosis of AS or AR from 2012 through 2016. We hypothesized that the usage of TAVR has increased particularly in patients with higher surgical risk and at urban teaching hospitals, whereas the number of patients receiving MT and the number of high-risk patients undergoing SAVR have decreased.

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Methods

Data were obtained from the Nationwide Readmissions Database (NRD), the largest, all-payer inpatient care database of the Agency for Healthcare Research and Quality's

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Healthcare Cost and Utilization Project (HCUP) containing an approximately 20% stratified sample of discharges from all hospitals in 27 US states.[12] Data from the NRD and its sister database, the National Inpatient Sample (NIS), have been used for multiple previous studies evaluating patients who have undergone TAVR.[13-16] From the NRD, we obtained de-identified discharge-level data files from 2012 through 2016. Each discharge record includes patient demographics and comorbidities, hospital characteristics, expected payment source, and discharge status. The NRD also collects primary and secondary (up to 35) discharge diagnoses and primary and secondary (up to 15) procedures based on the International Classification of Diseases, Clinical Modification codes (ICD-9-CM for 2012 through 2015 third quarter, ICD-10-CM for 2015 fourth quarter through 2016). From 2012 through 2016, participation in the HCUP NRD increased from 18 to 27 states.

Patient linkage numbers facilitate tracking individual patients across multiple hospitalizations, however, because each annual NRD data set is independent, individual patients cannot be tracked between years. Therefore, the study population included all patients who were admitted with aortic valve disease and discharged from January 1 through June 30 in each calendar year, allowing for 6 months of follow-up for every patient. The index admission (IA) was defined as the patient's first discharge with a primary or secondary diagnosis of nonrheumatic aortic valve stenosis or regurgitation, which was identified based upon ICD-9-CM (424.1) and ICD-10-CM (I35.0, I35.1, I35.2, I35.8, I35.9) codes, plus at least one of the following procedures or diagnoses: SAVR (ICD-9-CM 35.21, 35.22; ICD-10-CM 02RF07Z, 02RF08Z, 02RF0JZ, 02RF0KZ), TAVR (ICD-9-CM 35.05, 35.06; ICD-10-CM 02RF37H, 02RF37Z, 02RF38H, 02RF38Z, 02RF3JH, 02RF3JZ, 02RF3KH, 02RF3KZ), congestive heart failure (CHF; ICD-9-CM 428.0, 428.1, 428.20, 428.21, 428.22, 428.23, 428.30, 428.31, 428.32, 428.33, 428.40, 428.41, 428.42, 428.43; ICD-10-CM I50.1, I50.20, I50.21, I50.22, I50.23, I50.30, I50.31, I50.32, I50.33, I50,40, I50.41, I50.42, I50.43), unstable angina (UA; ICD-9-CM 411.1; ICD-10-CM I20.0), non−ST-elevation myocardial infarction (NSTEMI; ICD-9-CM 410.7 410.70 410.71 410.72; ICD-10-CM I21.4) or syncope (ICD-9-CM 780.2; ICD-10-CM R55) as any of up to 15 procedures or any of up to 35 diagnoses. We excluded 2011 data because TAVR was not FDA-approved until November of that year; only 21 patients in the NRD underwent TAVR in 2011.

Treatment strategy was classified as SAVR, TAVR, or MT. ICD-CM codes were used to identify patients undergoing SAVR and TAVR during the IA or within 180 days of the IA discharge date. Patients not undergoing SAVR or TAVR within 180 days of IA discharge were categorized as receiving MT.

The primary independent variable was treatment year. Among explanatory variables, we assessed for patient age (≤64, 65 to 74, 75 to 84, ≥85 years), sex, 2 health status variables constructed by NRD (severity of illness and risk of mortality) and the number of comorbid diagnoses reported during IA (1 to 10, 11 to 15, 16 to 20, 21 to 35). Age and number of diagnoses were converted to categorical variables because their relationships with SAVR, TAVR, and MT were highly nonlinear; all other predictors were presented as categorical variables by the NRD. Using 3M All Patient Refined Diagnosis Related Groups,[17,18] NRD classifies severity of illness into minor (including cases with no comorbidity or complications), moderate, major, and extreme loss of function. Similarly, risk of mortality is categorized into minor, moderate, major, and extreme likelihood of dying.

We also assessed both for patient insurance status (Medicare, Medicaid, private, self-pay, no charge/other) and neighborhood median household income as a proxy of patient socioeconomic status, and county population density as a proxy of urban/rural location. Quartiles of neighborhood median household income for patient ZIP code were defined each year (e.g., in 2016, the quartiles were defined as $1-42,999, $43,000-53,999, $54,000-70,999, and $71,000 or more). NRD also included county population density classification constructed by National Center for Health Statistics (less than 249,999, 250,000-999,999, fringe counties of ≥1 million, central counties of ≥1 million population).

For hospital characteristics, we assessed for ownership (for-profit private; not-for-profit private; government, nonfederal), size (small, medium, large per NRD criteria by region and teaching status[19]), and status as an urban teaching hospital (urban non-teaching, rural, urban teaching,).

Using Pearson Chi-squared tests, we examined systematic differences in the rates of SAVR, TAVR, and MT between 2012 and 2016, and assessed for systematic differences between treatment strategy and each explanatory variable.

For multivariate analysis, we employed a multinomial logistic (MNL) model to evaluate the factors associated with treatment strategy. We tested 2 MNL models: the first model used SAVR as the base outcome (which generated 2 sets of coefficient estimates, TAVR vs SAVR, and MT vs SAVR), and the second model used MT as the base outcome (which generated SAVR vs MT and TAVR vs MT). Coefficients of MNL models were converted to relative risk ratios (RRR).[20,21]

We performed 3 sensitivity analyses. First, we defined IA using just non-rheumatic AS or AI as any admission diagnosis without considering other conditions (i.e., SAVR, TAVR, CHF, UA, NSTEMI, or syncope). Second, we performed the analysis defining IA using only a primary diagnosis of AS or AI. Third, we repeated the analysis using 3-month and 9-month follow-up periods by allowing IA from January through September or January through March respectively.

This study was exempt from the requirements of the Institutional Review Board at the University of Nebraska Medical Center because the NRD contains no patient-identifiable information. All analyses were conducted with Stata MP v14.2 and accounted for the discharge weighting in the HCUP NRD survey design in order to produce nationally representative estimates.

Results

The sample population included 366,909 patients with IA discharges for aortic valve disease and one of the following procedures or diagnoses: SAVR (n = 64,695), TAVR (n = 18,107), CHF (n = 276,955), UA (n = 11,074), NSTEMI (n = 47,749), or syncope (n = 21,858).

Table 1
Patient characteristics and neighborhood information among total sample population and stratified by treatment strategy (No. (%))

	Total sample (n = 366909)	SAVR (n = 71704)	TAVR (n = 26173)	MT (n = 269032)	p Value
Age category					p < 0.01
64 or less	47077 (13.2)	20399 (43.9)	1062 (2.1)	25616 (54.0)	-
65-74	71762 (19.6)	24171 (33.9)	3813 (5.0)	43778 (61.1)	-
75-84	117206 (32.0)	22780 (19.7)	10333 (8.3)	84093 (72.0)	-
85 or above	130864 (35.2)	4354 (3.4)	10965 (8.0)	115545 (88.6)	-
Women	177681 (48.7)	24405 (14.1)	12145 (6.4)	141131 (79.5)	p < 0.01
Severity of illness					p < 0.01
Minor loss of function	17761 (4.9)	4918 (27.9)	152 (0.8)	12691 (71.3)	-
Moderate loss of function	134278 (37.2)	32093 (24.0)	3775 (2.7)	98410 (73.3)	-
Major loss of function	164340 (44.5)	27935 (17.3)	10948 (6.4)	125457 (76.3)	-
Extreme loss of function	50530 (13.4)	6758 (14.1)	11298 (21.5)	32474 (64.4)	-
Risk of mortality					p < 0.01
Minor likelihood of dying	21914 (6.1)	11029 (51.0)	1363 (5.6)	9522 (43.4)	-
Moderate likelihood of dying	148353 (40.8)	32363 (22.1)	12622 (7.9)	103368 (70.0)	-
Major likelihood of dying	152437 (41.3)	21673 (14.4)	10519 (6.6)	120245 (79.0)	-
Extreme likelihood of dying	44205 (11.8)	6639 (15.8)	1669 (3.6)	35897 (80.6)	-
Number of diagnoses					p < 0.01
1-10	48545 (13.8)	18923 (39.4)	3011 (5.5)	26611 (55.1)	-
11-15	111841 (30.6)	24060 (21.3)	8277 (6.8)	79504 (71.9)	-
16-20	115774 (31.3)	16990 (14.9)	9137 (7.5)	89647 (77.6)	-
21-35	90749 (24.3)	11731 (13.6)	5748 (6.4)	73270 (80.1)	-
Insurance status					p < 0.01
Medicare	311844 (85.2)	49467 (16.1)	24362 (7.4)	238013 (76.5)	-
Medicaid	11843 (3.0)	3319 (28.6)	244 (2.0)	8280 (69.4)	-
Private	35300 (9.6)	16735 (48.8)	1221 (3.2)	17346 (48.0)	-
Self-pay	2733 (0.8)	824 (30.9)	87 (2.7)	1822 (66.4)	-
No charge/other	5188 (1.4)	1359 (27.4)	259 (5.4)	3570 (67.3)	-
Neighborhood median household income					p < 0.01
Bottom quartile	86423 (24.9)	15393 (17.9)	5117 (5.6)	65910 (76.5)	-
Second quartile	91441 (26.1)	18112 (20.3)	6224 (6.6)	67106 (73.1)	-
Third quartile	94957 (25.5)	19187 (20.8)	7075 (7.2)	68697 (72.0)	-
Top quartile	94087 (23.5)	19012 (20.6)	7757 (7.6)	67319 (71.8)	-
Patient urban-rural classification					p < 0.01
Counties < 249,999	88376 (28.6)	18706 (21.2)	5962 (6.5)	63709 (72.3)	-
Counties 250,000-999,999	78109 (20.6)	16786 (22.0)	5625 (7.0)	55698 (71.0)	-
Fringe counties, ≥1 million	97908 (27.4)	18372 (19.2)	7697 (7.1)	71839 (73.7)	-
Central counties, ≥1 million	102516 (23.4)	17841 (17.4)	6889 (6.4)	77786 (76.2)	-

(i) Percentages adjusted for HCUP-NRD discharge weights to generate national estimates, accounting for slight deviation from the percentage calculated from the raw numbers.

(ii) Percentages in total sample are column percentages. Percentages in subsample population (SAVR, TAVR, and MT) are row percentages.

The average age was 77.8 years, and 48.7% of the study population was female. Fifty-eight percent (57.9%) of patients had major or extreme loss of function due to severity of illness, and 53.0% of patients had major or extreme likelihood of dying. Eighty-five percent (85.2%), 3.0%, and 9.6% of patients were covered by Medicare, Medicaid, and private insurance, respectively (Table 1).

The number of patients hospitalized for aortic valve disease in the first half of each calendar year increased by 48.1% from 57,516 in 2012 to 85,165 in 2016. Overall, from 2012 to 2016, January through June, 71,704 (19.9%), 26,173 (6.7%), and 269,032 (73.4%) patients received SAVR, TAVR, and MT, respectively. In 2012, 21.9%, 2.6%, and 75.5% of patients received each therapy, respectively, however, by 2016, the proportion undergoing SAVR and MT decreased to 18.5% and 69.0%, whereas the TAVR group increased to 12.5% (Table 2).

Subgroups stratified by patient, neighborhood, and hospital characteristics showed similar trends (Figures 1 and 2, $p < 0.01$ for all). Of note, among the patients ≥75 years of age, the proportion of patients undergoing TAVR increased rapidly, exceeding the proportion undergoing SAVR in 2016 (Figure 1, 9.3% for SAVR and 15.1% for TAVR). A similar trend was observed for patients with high severity of illness (i.e., major and extreme loss of function, Figure 1, 14.5% for SAVR and 17.3% for TAVR). Furthermore, among women (Figure 2), patients with high predicted mortality (Figure 2), and patients hospitalized in a large hospital (Figure 2) or in a teaching hospital (Figure 2), the proportions receiving SAVR and TAVR were similar by 2016. The same was true for patients at not-for-profit hospitals (Appendix Figure H), with >20 inpatient diagnoses (Appendix Figure B), or living in an urban area (Appendix Figure D).

Table 2
Treatment strategy, year, and hospital characteristics among total sample population and stratified by treatment strategy (No. (%))

	Total sample (n = 366909)	SAVR (n = 71704)	TAVR (n = 26173)	MT (n = 269032)	p Value
Treatment strategy					p < 0.01
SAVR	71704 (19.9)	71704 (100)	0 (0.0)	0 (0.0)	-
TAVR	26173 (6.7)	0 (0)	26173 (100)	0 (0.0)	-
MT	269032 (73.4)	0 (0)	0 (0)	269032 (100)	-
Year					p < 0.01
2012	57516 (18.2)	12290 (21.9)	1557 (2.6)	43669 (75.5)	-
2013	65880 (19.4)	13608 (20.7)	3040 (4.5)	49232 (74.8)	-
2014	69121 (19.7)	14012 (20.5)	4045 (5.6)	51064 (73.9)	-
2015	89227 (21.8)	16247 (18.4)	6904 (7.6)	66076 (74.0)	-
2016	85165 (20.9)	15547 (18.5)	10627 (12.5)	58991 (69.0)	-
Hospital ownership					p < 0.01
Private, investor-owned	43434 (10.7)	7806 (17.9)	1349 (2.9)	34279 (79.2)	-
Private, not-for-profit	283908 (79.2)	57237 (20.6)	21957 (7.2)	204714 (72.2)	-
Government, non-federal	39567 (10.1)	6661 (16.8)	2867 (6.9)	30039 (76.3)	-
Hospital size					p < 0.01
Small	36119 (11.0)	3892 (11.4)	768 (1.9)	31459 (86.7)	-
Medium	89810 (23.1)	14101 (16.1)	4004 (4.1)	71705 (79.8)	-
Large	240980 (65.9)	53711 (22.7)	21401 (8.5)	165868 (68.8)	-
Hospital teaching status					p < 0.01
Urban, non-teaching	109350 (27.6)	15686 (14.9)	2208 (2.0)	91456 (83.1)	-
Rural	22285 (8.3)	1215 (5.7)	237 (1.0)	20833 (93.3)	-
Urban, teaching	235274 (64.1)	54803 (24.0)	23728 (9.5)	156743 (66.5)	-

(i) Percentages adjusted for HCUP-NRD discharge weights to generate national estimates, accounting for slight deviation from the percentage calculated from the raw numbers.

(ii) Percentages in total sample are column percentages. Percentages in subsample population (SAVR, TAVR, and MT) are row percentages.

In multivariable analysis using the MNL model, estimates of TAVR versus SAVR showed that from 2012 to 2016, a patient's likelihood of receiving TAVR relative to SAVR increased by 4.57-fold (RRR 4.57, 95% confidence interval [CI] 4.21 to 4.97) when adjusting for patient, hospital, and neighborhood characteristics. Patients ≥85 years of age (RRR 51.2, 95% CI 46.1 to 56.7) and those with extreme loss of function (RRR 35.7, 95% CI 29.0 to 43.8) were most likely to undergo TAVR rather than SAVR. In MNL multivariable analysis for TAVR versus MT, the likelihood of receiving TAVR relative to MT continuously increased from 2012 through 2016 (RRR 4.41 vs 2012, 95% CI 4.08 to 4.77) (Table 3).

In the first sensitivity analysis, when we expanded the sample population by defining IA as any admission for AS or AR, regardless of other conditions (i.e., SAVR, TAVR, CHF, UA, NSTEMI or syncope), we captured 244,432 more patients (n = 611,341). Among the additional patients, 98.4% (n = 240,468) patients received MT, and numbers of SAVR and TAVR remained virtually unchanged. The estimates for SAVR versus TAVR in the multivariate MNL model were similar both in magnitude and statistical significance as compared with the main analysis (Appendix Table). In the second sensitivity analysis, when we restricted the sample population to patients only with a primary diagnosis of AS or AR (n = 101,834), 19.6% of SAVR, 3.8% of TAVR, and 92.9% of MT patients were eliminated. The MNL models in this sensitivity analysis remained similar to the main analysis (data not shown). In the third sensitivity analysis, when we looked at a 3-month window from IA (n = 519,882, SAVR 20.1%, TAVR 6.5%, MT 73.4%) and a 9-month window from IA (n = 195,427, SAVR 19.3%, TAVR 6.6%, MT 74.1%), the rates of each of the 3 therapies and the multivariate MNL model estimates (data not shown) remained similar to the 6-month main analysis.

Discussion

In a large, nationally-representative sample, the number of patients hospitalized for aortic valve disease increased 48.1% from 2012 through 2016. The likelihood of receiving TAVR increased with a RRR of 4.57 relative to SAVR and 4.41 relative to MT, a novel finding. However, not all patients and hospitals absorbed TAVR equally: increasing age, female sex, severity of illness rating, high number of diagnoses, not-for-profit hospital ownership, large hospital size, and teaching hospital status were associated with a higher prevalence of TAVR.

Increasing patient age was associated with increased use of TAVR and decreased use of SAVR. The potential for future growth in TAVR remains enormous due to the high prevalence of aortic valve disease in elderly patients, the overall aging of the US population, and anticipated expansion of TAVR to low-surgical risk patients. Thus, from a public health perspective, knowledge of trends in aortic valve disease is necessary to ensure adequate allocation of medical and financial resources to care for the ever-increasing number of aortic valve patients. Our study showed a 5-year increase of 48.1% in patients hospitalized for aortic valve disease, likely reflecting both the aging of the population and the increased availability of TAVR. A 2013 meta-analysis of 7 studies including 9,723 patients reported a

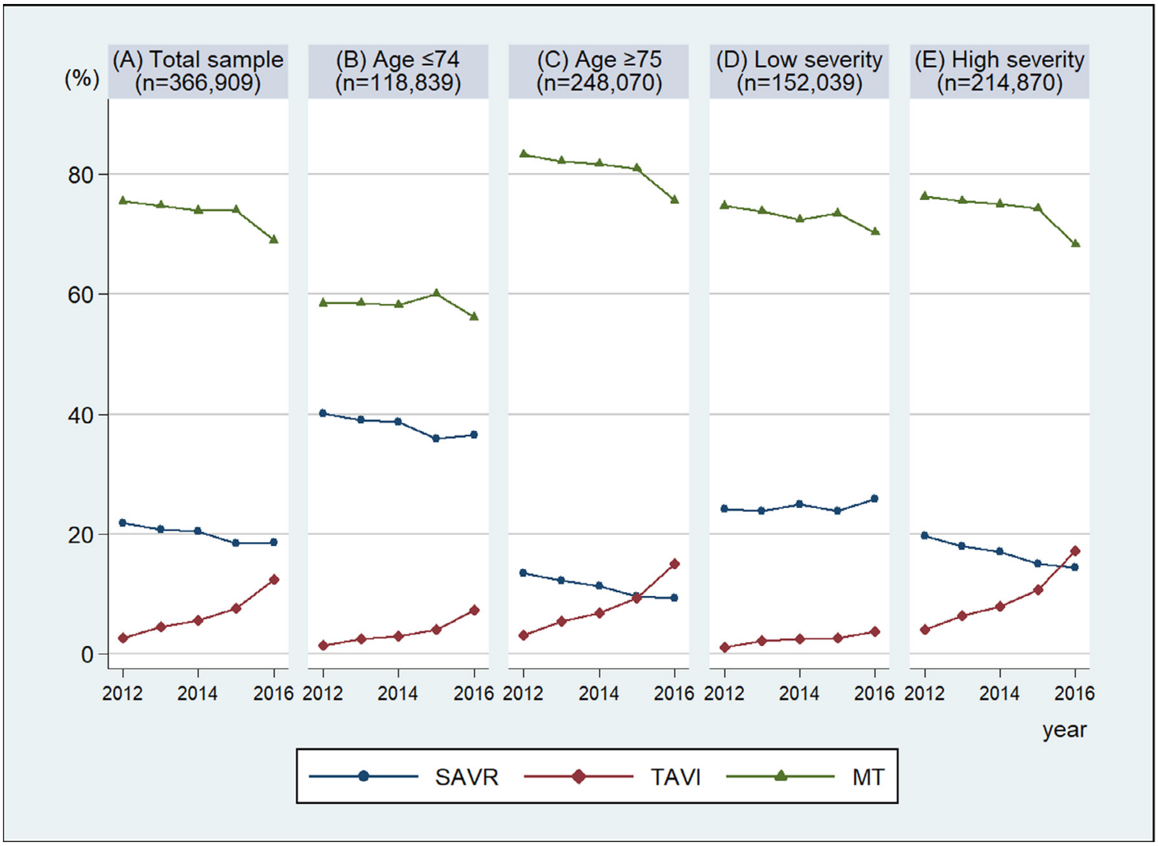

Figure 1. Trends in surgical aortic valve replacement (SAVR), transcatheter aortic valve replacement (TAVR), and medical therapy (MT) from 2012 to 2016: total sample population and stratified by age and severity of illness.
Notes: (i) Severity of illness: (D) low (minor or moderate loss of function) versus (E) high (major or extreme loss of function).
(ii) Percentages were adjusted for Healthcare Cost and Utilization Project Nationwide Readmissions Database (HCUP-NRD) discharge weights to generate national estimates.

prevalence of AS of 12.4% in patients aged ≥75 years including 3.4% with severe AS.[22] A 2017 meta-analysis of 56 studies in 37 countries including 42,965 patients reported the prevalence of AS to be 4.5%, comprised of 2.8% (95% CI 1.4% to 4.1%) of patients aged 60 to 74 years and 13.1% (95% CI 8.2% to 17.9%) of patients aged >75 years; 19.9% (95% CI 12.8% to 26.9%) of AS was classified as severe, corresponding to an estimated 781,773 (95% CI 542,923 to 1,063,142) patients in the US, and >40% of patients did not undergo any sort valve replacement therapy.[23]

Increasing severity of illness was associated with a preference for TAVR over SAVR. The evidence supporting this practice is historical: the pivotal randomized controlled trials comparing mortality following TAVR and SAVR showed equipoise for intermediate-risk patients[4,5,24]; for high-risk patients, the trials diverged with one showing equipoise[2] and another showing TAVR to be superior.[3] Recent data regarding low-risk patients[25,26] will likely lead to a future increase in TAVR and decrease in SAVR in this patient population.

Patients treated at large hospitals and urban teaching hospitals were more likely to undergo valve replacement than patients treated at small hospitals, urban nonteaching hospitals, and rural hospitals; hospitals categorized as not-for-profit and government, nonfederal were more likely to provide TAVR but not SAVR than for-profit private hospitals. As new data and procedural techniques emerge rapidly, they are incorporated into clinical practice unequally between different types of hospitals: in our study, the rates of increase in TAVR and decrease in both SAVR and MT confirm that large urban teaching not-for-profit hospitals are far faster to adopt novel evidence-based practices for the treatment of aortic valve disease than their small, rural, non-teaching, or for-profit counterparts.

Trends in the care of patients with aortic valve disease require much more research at the national level. Factors limiting access to TAVR must be identified and rectified. Also, whereas the exact costs of SAVR, TAVR, and MT are unknown, they are estimated to total a combined $10.2 billion annually in the US.[27] Across several studies, TAVR has been associated with increased procedural costs but decreased postprocedural resource utilization in comparison to SAVR; cost effectiveness estimates vary widely, particularly as a result of varying costs in different healthcare systems.[28] Whereas either valve replacement modality carries higher-up front costs than MT, as MT is increasingly reserved for only higher-risk patients, their frequent

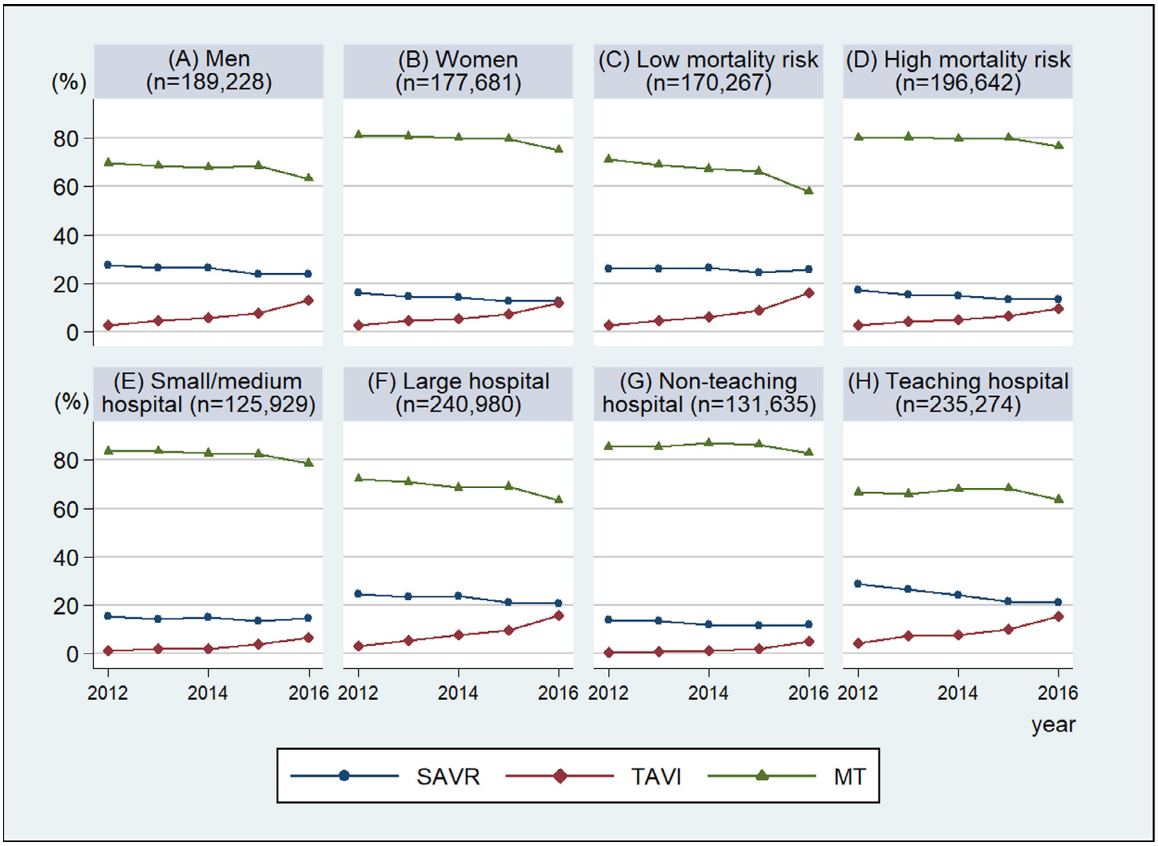

Figure 2. Trends in surgical aortic valve replacement (SAVR), transcatheter aortic valve replacement (TAVR), and medical therapy (MT) from 2012 to 2016: stratified by sex, risk of mortality, hospital size, and hospital teaching status.
Notes: (i) Risk of mortality: (C) low (minor or moderate likelihood of dying) versus (D) high (major or extreme likelihood of dying).
(ii) Nonteaching hospital category in panel (G) includes nonteaching hospitals in urban area and any hospitals in rural area.
(iii) Percentages were adjusted for HCUP-NRD discharge weights to generate national estimates.

readmissions and on-going medical care may become more expensive than valve replacement procedures.

Strengths and Limitations

Previous studies have examined the use of SAVR and TAVR, but our novel study also includes the population treated with MT. Furthermore, our unique January-through-June study methodology allowed us to obtain 6-months of postdischarge follow-up data for 366,909 patients with admissions for aortic valve disease undergoing valve replacement or symptomatic with CHF, UA, NSTEMI, and/or syncope. In contrast, most previous studies of aortic valve disease in HCUP data have employed the NIS, which does not provide unique patient identifiers, thus rendering it impossible to track patients across multiple admissions.[29-31] NIS studies can only examine outcomes per discharge, whereas our NRD methodology allowed 6-month follow-up on a per-patient basis, a more relevant measure for SAVR, TAVR, and MT.

Our study methodology has several important limitations. First, ICD-9-CM codes do not permit differentiation between AS and AR. The prevalence of moderate or severe AR is only approximately 0.5%,[32] and AR therapy has changed minimally with the advent of TAVR, so AR is unlikely to have contributed to the trends in therapy observed in this study: the trends observed in this study are principally attributable to AS therapy.

Neither ICD-9-CM nor ICD-10-CM codes quantify the severity of aortic valve dysfunction. Most patients with non-severe valve disease do not undergo valve replacement unless SAVR is performed for moderate AS or AR at the time of another cardiac surgery, typically coronary artery bypass grafting. Thus, we recognize the bias that patients with less severe valvular disease will generally be classified in the MT group. To mitigate this bias, we restricted our primary analysis to patients with a concomitant diagnosis suggesting significant AS or AR (i.e., SAVR, TAVR, CHF, UA, NSTEMI, and syncope): as seen in the first sensitivity analysis, this concomitant diagnosis eliminated 244,432 patients, 98.4% of whom received medical therapy, suggesting that nonsevere aortic valve disease was present. Of course, billing codes cannot determine precisely what fraction of patients hospitalized for aortic valve disease specifically had severe aortic stenosis, the only FDA-approved indication for TAVR. Still, indications will change: the PARTNER 3[25] and Evolut Low Risk[26] trials demonstrated safety and efficacy of TAVR in low-surgical-risk patient; the on-going EARLY TAVR trial (NCT03042104) is studying TAVR in severe, asymptomatic

Table 3
Association of year, patient characteristics, and hospital characteristics with treatment strategy (n = 366,909)

	TAVR vs. SAVR RRR (95% CI)	SAVR vs. MT RRR (95% CI)	TAVR vs. MT RRR (95% CI)
Year			
2012	1 [reference]	1 [reference]	1 [reference]
2013	1.79 (1.64-1.96)	1.00 (0.96-1.04)	1.78 (1.64-1.94)
2014	2.13 (1.95-2.33)	0.96 (0.92-0.99)	2.04 (1.87-2.21)
2015	2.84 (2.61-3.09)	0.90 (0.87-0.94)	2.56 (2.37-2.77)
2016	4.57 (4.21-4.97)	0.96 (0.93-1.00)	4.41 (4.08-4.77)
Age category			
64 or less	1 [reference]	1 [reference]	1 [reference]
65-74	2.64 (2.39-2.92)	1.07 (1.03-1.11)	2.84 (2.57-3.13)
75-84	8.51 (7.72-9.37)	0.62 (0.59-0.64)	5.25 (4.77-5.77)
85 or above	51.2 (46.1-56.7)	0.09 (0.09-0.10)	4.81 (4.37-5.30)
Women	1.29 (1.24-1.34)	0.62 (0.61-0.63)	0.80 (0.77-0.83)
Severity of illness			
Minor loss of function	1 [reference]	1 [reference]	1 [reference]
Moderate loss of function	3.16 (2.61-3.84)	1.89 (1.79-1.99)	5.97 (4.94-7.23)
Major loss of function	17.8 (14.6-21.7)	2.25 (2.12-2.39)	40.2 (33.3-48.8)
Extreme loss of function	35.7 (29.0-43.8)	2.58 (2.38-2.79)	92.0 (75.3-112)
Risk of mortality			
Minor likelihood of dying	1 [reference]	1 [reference]	1 [reference]
Moderate likelihood of dying	0.55 (0.51-0.60)	0.56 (0.53-0.58)	0.31 (0.28-0.33)
Major likelihood of dying	0.16 (0.14-0.17)	0.41 (0.39-0.43)	0.06 (0.06-0.07)
Extreme likelihood of dying	0.01 (0.01-0.01)	0.44 (0.41-0.48)	0.00 (0.00-0.00)
Number of diagnoses			
1-10	1 [reference]	1 [reference]	1 [reference]
11-15	1.47 (1.38-1.57)	0.44 (0.43-0.46)	0.65 (0.61-0.69)
16-20	1.95 (1.82-2.08)	0.27 (0.26-0.28)	0.53 (0.49-0.56)
21-35	1.58 (1.46-1.70)	0.22 (0.21-0.23)	0.34 (0.32-0.37)
Insurance status			
Medicare	1 [reference]	1 [reference]	1 [reference]
Medicaid	0.57 (0.47-0.68)	0.86 (0.81-0.91)	0.49 (0.41-0.58)
Private	0.48 (0.44-0.53)	1.87 (1.80-1.94)	0.91 (0.83-0.99)
Self-pay	0.65 (0.50-0.85)	0.87 (0.78-0.97)	0.56 (0.44-0.73)
No charge/other	0.72 (0.60-0.85)	1.02 (0.94-1.12)	0.73 (0.62-0.87)
Neighborhood median household income			
Bottom quartile	1 [reference]	1 [reference]	1 [reference]
Second quartile	0.94 (0.89-1.00)	1.34 (1.30-1.38)	1.26 (1.19-1.33)
Third quartile	0.93 (0.88-0.99)	1.43 (1.38-1.47)	1.32 (1.26-1.40)
Top quartile	0.90 (0.84-0.95)	1.61 (1.56-1.67)	1.44 (1.37-1.53)
Patient urban-rural classification			
Counties <249,999	1 [reference]	1 [reference]	1 [reference]
Counties 250,000-999,999	0.93 (0.88-0.99)	0.72 (0.69-0.74)	0.67 (0.63-0.71)
Fringe counties, ≥1 million	1.09 (1.02-1.16)	0.63 (0.61-0.65)	0.68 (0.65-0.72)
Central counties, ≥1 million	0.93 (0.88-0.99)	0.51 (0.50-0.53)	0.48 (0.45-0.51)
Hospital ownership			
Private, investor-owned	1 [reference]	1 [reference]	1 [reference]
Private, not-for-profit	1.33 (1.24-1.43)	0.87 (0.83-0.90)	1.15 (1.08-1.23)
Government, non-federal	1.77 (1.61-1.94)	0.54 (0.52-0.57)	0.96 (0.88-1.04)
Hospital size			
Small	1 [reference]	1 [reference]	1 [reference]
Medium	1.62 (1.45-1.80)	1.57 (1.49-1.65)	2.54 (2.30-2.79)
Large	2.63 (2.38-2.91)	2.88 (2.75-3.02)	7.58 (6.91-8.31)
Hospital teaching status			
Urban, non-teaching	1 [reference]	1 [reference]	1 [reference]
Rural	1.34 (1.13-1.57)	0.28 (0.26-0.30)	0.37 (0.32-0.43)
Urban, teaching	2.85 (2.69-3.02)	2.14 (2.09-2.20)	6.11 (5.78-6.45)

aortic stenosis; and the on-going TAVR UNLOAD trial is studying TAVR in moderate aortic stenosis (NCT02661451). Ultimately, we believe that, because all included patients had both valve disease and an associated procedure or symptom severe enough to qualify as billing diagnoses for hospital admission, the patient populations in the SAVR, TAVR, and MT groups were adequately comparable for a meaningful analysis.

Our main analysis used 6 months of follow-up, and some patients who received MT during the study period may have subsequently undergone SAVR or TAVR, although results did not change appreciably in the third sensitivity analysis looking at 3- and 9-month follow-up. The rare patients undergoing balloon aortic valvuloplasty would also be categorized as receiving MT, but this seems appropriate given the short duration of effect of this procedure. Conclusively, despite these limitations, this study provides important and novel information regarding the variation in use of SAVR, TAVR, and MT in the US.

Conclusions

From 2012 through 2016, the use of TAVR increased at the expense of both SAVR and MT. The greatest use of TAVR was associated with patients at elevated surgical risk and hospitals that were large, not-for-profit, and urban teaching hospitals. Expected expansion of TAVR indications portends continued growth of TAVR and reduction in SAVR and MT. The inequitable distribution of TAVR therapy must be addressed.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2019.05.044.

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