# Transcatheter Versus Surgical Aortic Valve Replacement in Patients With Prior Coronary Artery Bypass Grafting

## Trends in Utilization and Propensity-Matched Analysis of In-Hospital Outcomes

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***Background***—A significant proportion of patients requiring aortic valve replacement (AVR) have undergone prior coronary artery bypass grafting (CABG). Reoperative heart surgery is associated with increased risk. Data on relative utilization and comparative outcomes of transcatheter (TAVR) versus surgical AVR (SAVR) in patients with prior CABG are limited.

***Methods and Results***—We queried the 2012 to 2014 National Inpatient Sample databases to identify isolated AVR hospitalizations in adults with prior CABG. In-hospital outcomes of TAVR versus SAVR were compared using propensity-matched analysis. Of 147 395 AVRs, 15 055 (10.2%) were in patients with prior CABG. The number of TAVRs in patients with prior CABG increased from 1615 in 2012 to 4400 in 2014, whereas the number of SAVRs decreased from 2285 to 1895 ($P_{trend}$<0.001). There were 3880 records in each group in the matched cohort. Compared with SAVR, TAVR was associated with similar in-hospital mortality (2.3% versus 2.4%; *P*=0.71) but lower incidence of myocardial infarction (1.5% versus 3.4%; *P*<0.001), stroke (1.4% versus 2.7%; *P*<0.001), bleeding complications (10.6% versus 24.6%; *P*<0.001), and acute kidney injury (16.2% versus 19.3%; *P*<0.001). Requirement for prior permanent pacemaker was higher in the TAVR cohort, whereas the incidence of vascular complications and acute kidney injury requiring dialysis was similar in the 2 groups. Average length of stay was shorter in patients undergoing TAVR.

***Conclusions***—TAVR is being increasingly used as the preferred modality of AVR in patients with prior CABG. Compared with SAVR, TAVR is associated with similar in-hospital mortality but lower rates of in-hospital complications in this important subset of patients. **(*Circ Cardiovasc Interv*. 2018;11:e006179. DOI: 10.1161/CIRCINTERVENTIONS.117.006179.)**

**Key Words:** acute kidney injury ■ aortic valve ■ coronary artery bypass grafting ■ myocardial infarction ■ stroke ■ transcatheter aortic valve replacement

Transcatheter aortic valve replacement (TAVR) is now a widely accepted therapeutic modality for patients with symptomatic severe aortic stenosis who are at prohibitive/high (class I) or intermediate (class IIa) risk for perioperative mortality after surgical aortic valve replacement (SAVR).[1] Because similar risk factors are responsible for the pathogenesis of coronary artery disease and aortic stenosis, a substantial number of patients requiring aortic valve replacement (AVR) have undergone prior coronary artery bypass grafting (CABG).[2] Up to one third of patients in the PARTNER (Placement of Aortic Transcatheter Valve Trial) and US CoreValve trials had a history of prior CABG.[3–7] Reoperative cardiac surgery is

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## WHAT IS KNOWN

- A substantial proportion of patients undergoing aortic valve replacement (AVR) have undergone prior coronary artery bypass grafting.
- Reoperative heart surgery is associated with a greater risk of morbidity and mortality.

## WHAT THE STUDY ADDS

- In patients with prior coronary artery bypass grafting undergoing AVR, the utilization of transcatheter AVR has increased relative to surgical AVR. Transcatheter AVR became the predominant modality of AVR in the United States in this subset of patients by the last quarter of 2012, with its relative utilization continuing to increase through the last quarter of 2014.
- Transcatheter AVR and surgical AVR are associated with similar in-hospital mortality in patients with prior coronary artery bypass grafting; however, transcatheter AVR is associated with a lower rate of in-hospital complications, shorter length of stay, and a lower requirement for skilled nursing services at discharge.

associated with greater risk of mortality and morbidity.[8,9] In fact, the 2017 European Society of Cardiology Guidelines for management of valvular heart disease include previous cardiac surgery and presence of intact bypass grafts at risk for damage during redo sternotomy as considerations for Heart Team decision making between TAVR versus SAVR in patients at increased surgical risk.[10] Recent data from Germany suggest a temporal increase in the use of TAVR in patients with prior CABG undergoing AVR.[11] Subgroup analyses of randomized trials, retrospective single-center studies, and a meta-analysis have reported noninferiority or even superiority of TAVR compared with SAVR in this high-risk subset of patients.[12–17] We hypothesized that the adoption of TAVR would have increased in patients with prior CABG undergoing AVR in the United States and that TAVR would be associated with more favorable short-term outcomes compared with SAVR in these patients.

# Methods

## Data Source

Data were obtained from the 2012 to 2014 National Inpatient Sample (NIS) database files. The NIS is a database of hospital inpatient stays and is sponsored by the Agency for Healthcare Research and Quality as a part of the Healthcare Cost and Utilization Project. The NIS is the largest all-payer inpatient care database that is publicly available and approximates a 20% stratified sample of all discharges from US hospitals in the participating states (n=45 at present). Each record in the NIS includes information on primary and secondary discharge diagnoses and procedures, demographics, hospital characteristics, expected payment source, total charges, discharge status, length of stay (LOS), and comorbidity measures. Discharge weights are provided that can be used to obtain national estimates.[18] Weighted data were used for all analyses in this study. The NIS data files are publicly available to other researchers for the purposes of reproducing our analyses. This study was considered exempt from Institutional Review Board approval because Healthcare Cost and Utilization Project-NIS contains deidentified patient information.

## Study Population

We used the *International Classification of Diseases*, Ninth Edition, Clinical Modification (ICD-9-CM) procedure codes to identify all AVR hospitalizations in patients aged ≥18 years (35.21 and 35.22 for SAVR; n=220 230 and 35.05 and 35.06 for TAVR; n=41 025). Records with missing data on in-hospital mortality (n=70) were first excluded. We then excluded records with concomitant use of percutaneous coronary intervention (n=2400), CABG (n=75 695), or other valvular procedures (n=44 015) during the AVR hospitalization. Finally, we excluded patients with a history of prior heart valve replacement (n=2415), yielding a final study cohort of 147 395 isolated AVR hospitalizations. Patients with a prior history of CABG (n=15 055) were identified using ICD-9-CM code V45.81. A list of ICD-9-CM codes used for selection of the study population is provided in Table I in the Data Supplement. We also performed a sensitivity analysis in which the study population was restricted to records with a concomitant secondary diagnosis of aortic stenosis (ICD-9-CM codes 395.0, 395.2, 396.2, 424.1, and 746.3; n=13 710).

## Baseline Characteristics

We used the following as baseline patient-level characteristics: demographics (age, sex, race, primary expected payer, median household income for patient's ZIP code) and relevant comorbidities (smoking, dyslipidemia, known coronary artery disease, prior myocardial infarction [MI], prior percutaneous coronary intervention, prior transient ischemic attack/stroke, atrial fibrillation, heart failure, diabetes mellitus, hypertension, obesity, peripheral vascular disease, carotid artery disease, prior permanent pacemaker [PPM], prior implantable cardioverter defibrillator, chronic renal failure, anemia, chronic pulmonary disease, coagulopathy, dementia, hypothyroidism, liver disease, fluid and electrolyte disorders, cancer, and neurological disorders).[19,20] Hospital-level characteristics were census region, bed size, and teaching status. A list of ICD-9-CM and Clinical Classification Software codes used to identify comorbidities is included in Table II in the Data Supplement.

## Study Outcomes

Our primary outcome of interest was all-cause, in-hospital mortality. Secondary outcomes of interest were MI, stroke, bleeding, vascular complications, acute kidney injury (AKI), AKI requiring dialysis, new requirement for PPM, average LOS, and discharge disposition among survivors. A list of ICD-9-CM codes used to define in-hospital complications is included in Table III in the Data Supplement. Prior studies have used this methodology to identify the included secondary outcomes.[21,22]

## Statistical Analysis

Survey-specific techniques accounting for the multilevel nature of the data were used for weighting to obtain national estimates as recommended by the Agency for Healthcare Research and Quality.[23,24] Baseline characteristics of patients with prior CABG undergoing TAVR versus SAVR were compared using the Rao-Scott $\chi^2$ test for categorical variables and survey-specific *t* test for continuous variables.

To reduce the confounding effect of between-group imbalances on outcomes, we used propensity score matching to assemble a matched cohort in whom patients with prior CABG undergoing TAVR versus SAVR were balanced on measured baseline characteristics. We used a nonparsimonious multivariable logistic regression model with the treatment assignment as the outcome variable and all covariates listed in Table 1, as well as discharge weights as covariates. Using a 1-to-1 greedy matching protocol and a caliper width of 0.2× the standard

**Table 1. Baseline Characteristics of Patients With Prior CABG Undergoing TAVR Versus SAVR Before and After Propensity Matching**

| | Before Matching | | | After Matching | | |
|---|---|---|---|---|---|---|
| Variable | SAVR (n=6170) | TAVR (n=8885) | *P* Value | SAVR (n=3880) | TAVR (n=3880) | *P* Value |
| Age, mean±SD (y) | 73.6±8.7 | 80.7±7.2 | <0.001 | 74.9±8.9 | 79.1±7.8 | <0.001 |
| <80 y | 72.4% | 36.2% | <0.001 | 63.0% | 50.4% | <0.001 |
| ≥80 y | 27.6% | 63.8% | <0.001 | 37.0% | 49.6% | <0.001 |
| Women | 18.6% | 25.8% | <0.001 | 20.2% | 22.3% | 0.35 |
| Race | | | | | | |
| White | 83.7% | 83.6% | 0.95 | 84.5% | 84.3% | 0.94 |
| Non-white | 10.6% | 9.2% | 0.24 | 9.4% | 9.5% | 1.00 |
| Missing | 5.7% | 7.2% | 0.14 | 6.1% | 6.2% | 1.00 |
| Comorbidities | | | | | | |
| Smoking | 5.9% | 2.7% | <0.001 | 4.3% | 4.0% | 0.90 |
| Dyslipidemia | 78.0% | 78.5% | 0.71 | 78.7% | 76.7% | 0.36 |
| Known CAD | 93.4% | 94.2% | 0.36 | 93.7% | 93.2% | 0.76 |
| Prior myocardial infarction | 19.4% | 21.8% | 0.11 | 20.2% | 21.3% | 0.66 |
| Prior PCI | 16.9% | 25.0% | <0.001 | 19.3% | 22.9% | 0.10 |
| Prior TIA/stroke | 10.9% | 12.9% | 0.09 | 11.7% | 12.4% | 0.76 |
| Atrial fibrillation | 46.9% | 41.4% | 0.004 | 45.9% | 44.3% | 0.58 |
| Heart failure | 43.6% | 76.2% | <0.001 | 56.1% | 64.0% | 0.001 |
| Diabetes mellitus | 43.4% | 41.8% | 0.41 | 44.1% | 45.2% | 0.69 |
| Hypertension | 82.3% | 85.2% | 0.04 | 84.3% | 83.8% | 0.83 |
| Obesity | 18.5% | 12.9% | <0.001 | 16.4% | 15.6% | 0.73 |
| Peripheral vascular disease | 21.3% | 33.4% | <0.001 | 24.6% | 28.9% | 0.07 |
| Carotid artery disease | 7.9% | 7.8% | 0.97 | 8.4% | 7.1% | 0.40 |
| Prior PPM | 7.6% | 14.3% | <0.001 | 9.7% | 11.7% | 0.20 |
| Prior ICD | 2.2% | 5.7% | <0.001 | 3.1% | 5.3% | 0.04 |
| Chronic renal failure | 21.5% | 38.8% | <0.001 | 25.9% | 34.0% | <0.001 |
| Anemia | 19.9% | 25.2% | 0.001 | 19.8% | 23.2% | 0.12 |
| Chronic pulmonary disease | 21.2% | 32.0% | <0.001 | 25.1% | 28.4% | 0.17 |
| Coagulopathy | 38.5% | 23.3% | <0.001 | 32.3% | 29.3% | 0.20 |
| Dementia | 1.2% | 3.8% | <0.001 | 1.2% | 2.7% | 0.05 |
| Hypothyroidism | 13.8% | 17.1% | 0.017 | 14.3% | 15.1% | 0.72 |
| Liver disease | 0.6% | 1.5% | 0.04 | 0.9% | 1.0% | 1.00 |
| Fluid and electrolyte disorder | 31.7% | 22.0% | <0.001 | 28.5% | 26.3% | 0.36 |
| Cancer | 2.0% | 3.5% | 0.018 | 2.6% | 2.6% | 1.00 |
| Neurological disorders | 8.4% | 8.0% | 0.69 | 8.2% | 7.2% | 0.50 |
| Hospital Characteristics | | | | | | |
| Hospital region | | | | | | |
| Northeast | 20.3% | 22.6% | 0.17 | 26.2% | 22.9% | 0.15 |
| Midwest | 25.4% | 23.5% | 0.34 | 26.3% | 22.0% | 0.06 |
| South | 35.1% | 36.3% | 0.61 | 33.2% | 37.4% | 0.09 |
| West | 19.3% | 17.6% | 0.40 | 14.3% | 17.7% | 0.08 |

(*Continued*)

Table 1. Continued

| Variable | Before Matching | | | After Matching | | |
|---|---|---|---|---|---|---|
| | SAVR (n=6170) | TAVR (n=8885) | *P* Value | SAVR (n=3880) | TAVR (n=3880) | *P* Value |
| Bed size | | | | | | |
| Small | 7.9% | 4.2% | <0.001 | 4.9% | 3.9% | 0.39 |
| Medium | 19.9% | 16.2% | 0.03 | 17.1% | 18.2% | 0.65 |
| Large | 72.3% | 79.6% | <0.001 | 78.0% | 78.0% | 1.00 |
| Teaching hospital | 72.4% | 90.0% | <0.001 | 81.8% | 86.6% | 0.01 |
| Primary expected payer | | | | | | |
| Medicare | 80.3% | 90.1% | <0.001 | 83.9% | 87.0% | 0.09 |
| Other | 19.7% | 9.9% | <0.001 | 16.1% | 13.0% | 0.09 |
| Median household income | | | | | | |
| 0 to 25th percentile | 21.4% | 20.9% | 0.74 | 21.4% | 20.6% | 0.75 |
| 26th to 50th percentile | 26.3% | 26.6% | 0.90 | 24.6% | 26.5% | 0.39 |
| 51st to 75th percentile | 26.7% | 25.2% | 0.35 | 26.8% | 26.2% | 0.82 |
| 76th to 100th percentile | 25.5% | 27.4% | 0.28 | 27.2% | 26.7% | 0.87 |

CAD indicates coronary artery disease; CABG, coronary artery bypass grafting; ICD, implantable cardioverter defibrillator; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement; and TIA, transient ischemic attack.



deviation of the logit of the propensity score, we matched 3880 patients with prior CABG undergoing TAVR with 3880 patients undergoing SAVR. We examined absolute standardized differences (ASD) for each variable between the 2 groups to assess the efficacy of the propensity score model. ASD represents differences in means or proportions divided by a pooled estimate of the SDs. An ASD of 0 for a variable indicates no bias, and values <10 suggest an inconsequential bias.[25] In the matched cohort, we used univariate logistic regression to compare in-hospital outcomes of patients with prior CABG undergoing TAVR versus SAVR.

In the unmatched cohort, complex samples multivariable logistic or linear regression models were used to compare in-hospital outcomes (in-hospital mortality, MI, stroke, bleeding, vascular complications, AKI, AKI requiring dialysis, requirement for new PPM, LOS) in patients with prior CABG undergoing TAVR versus SAVR. All variables included in Table 1 were used in the regression models. Log-transformed LOS was used as the dependent variable in the respective model given its positively skewed distribution. Data were complete on all covariates except race (6.7% missing), median household income (1.6% missing), and primary expected payer (0.1% missing). For variables with <5% missing data, the missing value was replaced with the dominant category. For variables with >5% missing data (only race), the missing value was treated as a separate category in the regression models. This approach has been used in prior studies.[21,26] We also separately examined in-hospital outcomes of patients undergoing endovascular or transapical TAVR compared with those undergoing SAVR.

Statistical analysis was conducted using SPSS version 23.0 (IBM Corp, Armonk, NY). All *P* values are 2-sided with a significance threshold of <0.05. Categorical variables are expressed as percentages and continuous variables as mean±standard deviation (SD). Odds ratios (OR) and 95% confidence intervals (CI) are used to report the results of regression analyses.

## Results

### AVR in Patients With Prior CABG

From 2012 to 2014, of 147 395 isolated AVR hospitalizations, 15 055 (10.2%) were in patients with a history of prior CABG. Of the total number of isolated AVRs, the proportion of those in patients with prior CABG increased from 9.2% in 2012 to 11.4% in 2014 ($P_{trend}$<0.001).

Of 15 055 patients with prior CABG undergoing AVR, 6170 (41%) underwent SAVR and 8885 (59%) underwent TAVR. The proportion of SAVR decreased, whereas that of TAVR increased during the study period ($P_{trend}$<0.001). In the first quarter of 2012, SAVR was the predominant modality of AVR, whereas by the fourth quarter of 2012, TAVR became the predominant modality of AVR in patients with prior CABG, with its utilization continuing to increase through the last quarter of 2014 (Figure 1).

In contrast, in patients without prior CABG undergoing AVR (n=132 340), although the proportion of SAVR decreased and that of TAVR increased, SAVR continued to be the predominant modality of AVR throughout the study period (Figure I in the Data Supplement).

### Baseline Characteristics

Compared with patients undergoing SAVR, those undergoing TAVR were older (mean age 80.7 years versus 73.6 years; *P*<0.001), more likely to be women (25.8% versus 18.6%; *P*<0.001), and more likely to be Medicare beneficiaries (90.1% versus 80.3%; *P*<0.001). The prevalence of most comorbidities, for example, prior percutaneous coronary intervention, heart failure, hypertension, peripheral vascular disease, prior PPM, prior implantable cardioverter defibrillator, chronic renal failure, anemia, chronic pulmonary disease, hypothyroidism, liver disease, and cancer, was higher in the TAVR cohort (*P*<0.05 for all). Smoking, atrial fibrillation, obesity, coagulopathy, and fluid and electrolyte disorders were less frequent in patients undergoing TAVR (*P*<0.05 for all). TAVR was more likely to be performed in

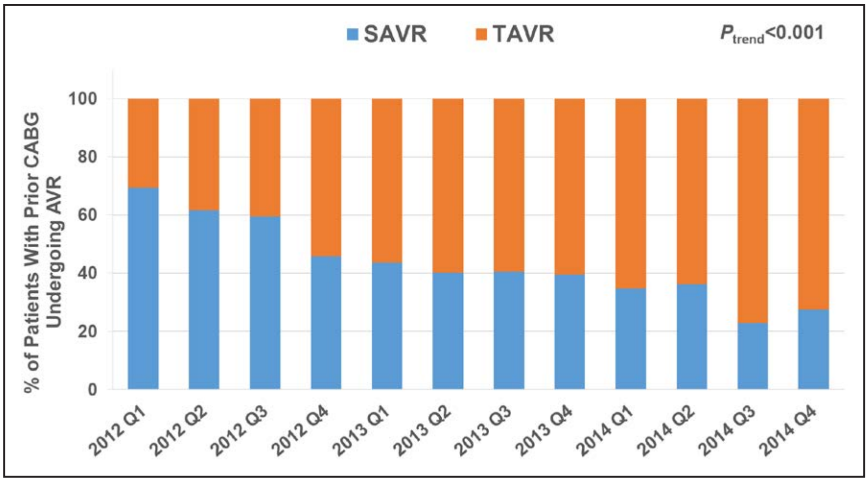


**Figure 1.** Temporal trends in utilization of TAVR and SAVR in patients with prior CABG. AVR indicates aortic valve replacement; CABG, coronary artery bypass grafting; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.

large, teaching hospitals (Table 1). Propensity scores were used to adjust for the effects of baseline patient and hospital characteristics. A matched cohort of 3880 patients each in the SAVR and TAVR groups with a similar propensity score was established. Matching resulted in a significant reduction in bias with ASD of <10% for most variables (Figure 2).

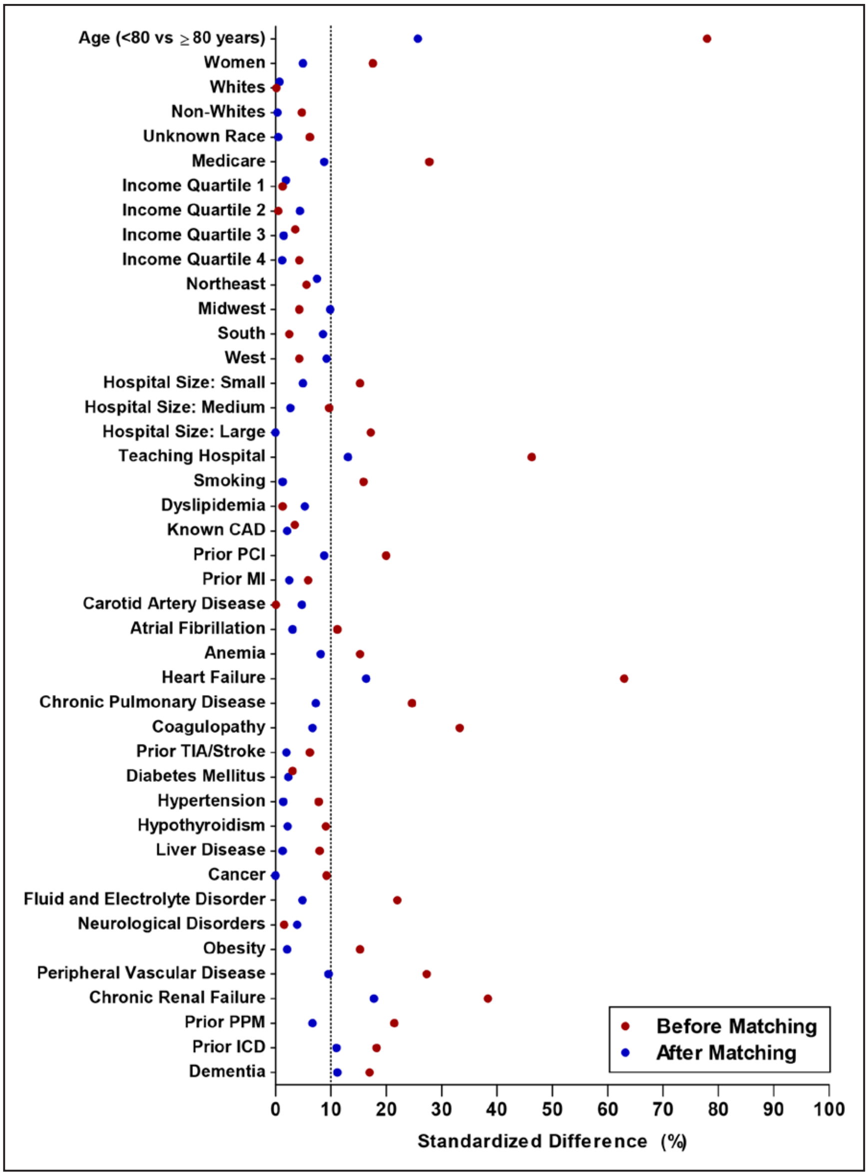


**Figure 2.** Absolute standardized differences in baseline characteristics of patients with prior CABG undergoing TAVR vs SAVR before and after propensity matching. CAD indicates coronary artery disease; ICD, implantable cardioverter defibrillator; MI, myocardial infarction; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; TAVR, transcatheter aortic valve replacement; and TIA, transient ischemic attack.

**Table 2. In-Hospital Outcomes of Patients With Prior CABG Undergoing TAVR Versus SAVR**

| | Before Matching | | | After Matching | | |
|---|---|---|---|---|---|---|
| | SAVR | TAVR | *P* Value | SAVR | TAVR | *P* Value |
| In-hospital mortality | | | | | | |
| % | 2.5% | 2.1% | … | 2.4% | 2.3% | … |
| Unadjusted OR (95% CI) | Ref. | 0.85 (0.54–1.34) | 0.48 | Ref. | 1.06 (0.79–1.42) | 0.71 |
| Adjusted OR* (95% CI) | Ref. | 0.75 (0.42–1.35) | 0.33 | … | … | … |
| Myocardial infarction | | | | | | |
| % | 2.7% | 1.9% | … | 3.4% | 1.5% | … |
| Unadjusted OR (95% CI) | Ref. | 0.69 (0.43–1.10) | 0.12 | Ref. | 0.45 (0.33–0.62) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.50 (0.29–0.87) | 0.01 | … | … | … |
| Stroke | | | | | | |
| % | 2.7% | 1.6% | … | 2.7% | 1.4% | … |
| Unadjusted OR (95% CI) | Ref. | 0.55 (0.34–0.89) | 0.03 | Ref. | 0.52 (0.37–0.72) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.41 (0.23–0.73) | 0.006 | … | … | … |
| Bleeding complications | | | | | | |
| % | 24.1% | 11.3% | … | 24.6% | 10.6% | … |
| Unadjusted OR (95% CI) | Ref. | 0.40 (0.32–0.49) | <0.001 | Ref. | 0.36 (0.32–0.41) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.37 (0.29–0.48) | <0.001 | … | … | … |
| Vascular complications | | | | | | |
| % | 5.5% | 5.3% | … | 5.4% | 5.5% | … |
| Unadjusted OR (95% CI) | Ref. | 0.96 (0.70–1.31) | 0.78 | Ref. | 1.03 (0.84–1.25) | 0.80 |
| Adjusted OR* (95% CI) | Ref. | 0.84 (0.57–1.21) | 0.35 | … | … | … |
| AKI | | | | | | |
| % | 17.8% | 16.7% | … | 19.3% | 16.2% | … |
| Unadjusted OR (95% CI) | Ref. | 0.92 (0.76–1.11) | 0.39 | Ref. | 0.81 (0.72–0.91) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.68 (0.53–0.88) | 0.003 | … | … | … |
| AKI requiring dialysis | | | | | | |
| % | 1.1% | 1.4% | … | 1.2% | 1.2% | … |
| Unadjusted OR (95% CI) | Ref. | 1.29 (0.68–2.42) | 0.44 | Ref. | 1.00 (0.66–1.52) | 1.00 |
| Adjusted OR* (95% CI) | Ref. | 0.64 (0.30–1.37) | 0.25 | … | … | … |
| Requirement for PPM | | | | | | |
| % | 5.2% | 10.1% | … | 5.4% | 8.9% | … |
| Unadjusted OR (95% CI) | Ref. | 2.05 (1.54–2.72) | <0.001 | Ref. | 1.71 (1.43–2.04) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 1.60 (1.13–2.26) | 0.007 | … | … | … |
| Length of stay† | | | | | | |
| Mean±SD, days | 8.7±5.9 | 6.5±5.0 | … | 9.1±6.0 | 6.6±5.1 | … |
| Unadjusted parameter estimate (95% CI) | Ref. | 0.75 (0.74–0.76) | <0.001 | Ref. | 0.73 (0.71–0.74) | <0.001 |
| Adjusted parameter estimate* (95% CI) | Ref. | 0.70 (0.69–0.71) | <0.001 | … | … | … |

AKI indicates acute kidney injury; CABG, coronary artery bypass grafting; CI, confidence intervals; OR, odds ratios; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; SD, standard deviation; and TAVR, transcatheter aortic valve replacement.

*Adjusted for demographics (age, sex, race), hospital characteristics (region, bed size, teaching status), and all comorbidities listed in Table 1.

†Unadjusted and adjusted parameter estimates reported for length of stay represent the antilog of the β coefficients [exp(β)] obtained from the log-transformed linear regression models.

## In-Hospital Outcomes

After propensity matching, patients undergoing TAVR had similar in-hospital mortality compared with those undergoing SAVR (2.3% versus 2.4%; OR, 1.06; 95% CI, 0.79–1.42). TAVR was associated with lower incidence of MI (1.5% versus 3.4%; OR, 0.45; 95% CI, 0.33–0.62), stroke (1.4% versus

2.7%; OR, 0.52; 95% CI, 0.37–0.72), bleeding (10.6% versus 24.6%; OR, 0.36; 95% CI, 0.32–0.41), and AKI (16.2% versus 19.3%; OR, 0.81; 95% CI, 0.72–0.91). The requirement for PPM was almost 2-fold higher in the TAVR cohort (8.9% versus 5.4%; OR, 1.71; 95% CI, 1.43–2.04), whereas the incidence of vascular complications (5.5% versus 5.4%; OR, 1.03; 95% CI, 0.84–1.25) and AKI requiring dialysis (1.2% versus 1.2%; OR, 1.00; 95% CI, 0.66–1.52) was similar in the 2 groups. Average LOS was shorter in the TAVR cohort (6.6 days versus 9.1 days; adjusted parameter estimate, 0.73; 95% CI, 0.71–0.74; Table 2). Certain variables, ie, age, heart failure, prior implantable cardioverter defibrillator, chronic renal failure, dementia, and hospital teaching status, were unbalanced (ASD>10%) between the 2 groups after propensity matching. After multivariable adjustment for these covariates in the propensity-matched cohort, results were largely unchanged (Table IV in the Data Supplement). Among patients surviving to discharge, those undergoing TAVR were more likely to be discharged home and less likely to require skilled nursing facility or home health services at discharge (Figure 3).

Similar results were obtained when in-hospital outcomes were compared between TAVR and SAVR groups in the unmatched cohort after multivariable risk adjustment (Table 2). In a sensitivity analysis restricted to records with a primary or secondary diagnosis of aortic stenosis, results were largely similar (Table V in the Data Supplement).

### Endovascular or Transapical TAVR Versus SAVR

Of 8885 patients with prior CABG who underwent TAVR, 7005 (78.8%) underwent endovascular and 1880 (21.2%) underwent transapical TAVR. In multivariable analysis, patients undergoing endovascular or transapical TAVR had similar in-hospital mortality as those undergoing SAVR. Both endovascular and transapical TAVR were associated with lower incidence of bleeding complications and shorter LOS compared with SAVR. Compared with SAVR, the incidence of stroke and AKI was lower and that of PPM implantation higher only for the endovascular TAVR cohort (Table 3). Similar results were seen with propensity score–matched analysis of in-hospital outcomes of endovascular or transapical TAVR versus SAVR (Tables VI and VII in the Data Supplement).

## Discussion

In our current study of ≈15 000 AVR hospitalizations in patients with prior CABG in the United States from 2012 to 2014, we report the following notable findings: (1) utilization of TAVR increased relative to SAVR, and TAVR became the predominant modality of AVR in this subset of patients by the last quarter of 2012; (2) patients undergoing TAVR were older and had significantly higher comorbidity burden; (3) TAVR and SAVR were associated with similar in-hospital mortality; (4) TAVR was associated with lower incidence of MI, stroke, bleeding complications, and AKI and shorter LOS compared with SAVR; (5) TAVR was associated with higher rates of PPM implantation.

Despite a decline in the mortality rates from >10% in pre-1980s to ≈5% in contemporary cardiac surgery practice, reoperative cardiac surgery continues to be associated with high rates of mortality and morbidity.[8,9] Reoperative AVR in patients with prior CABG is technically challenging because of calcification of the aortic arch, scarring of the mediastinum, and risk of damage to the bypass grafts.[27,28] With the advent of TAVR in the last decade, there has been a paradigm shift in the management of patients with prior CABG requiring AVR. A recent registry-based analysis from Germany examined the utilization of TAVR and SAVR in patients with prior CABG undergoing AVR. The number of TAVR procedures increased from 18 in 2007 to 1191 in 2012, whereas the number of SAVRs decreased from 471 to 179. In 2013, TAVR was the preferred modality of AVR in 90% of the patients with prior CABG.[11] We report similar trends in the United States with TAVR being used in ≈70% of patients with prior CABG undergoing AVR in 2014. The proportion of TAVR in these patients would likely have increased even further in more recent years.

Ours is the largest study to date to examine the comparative in-hospital outcomes of TAVR versus SAVR in patients with prior CABG and is representative of the overall US experience. We report similar rates of in-hospital mortality in patients undergoing TAVR versus SAVR. Prior data on

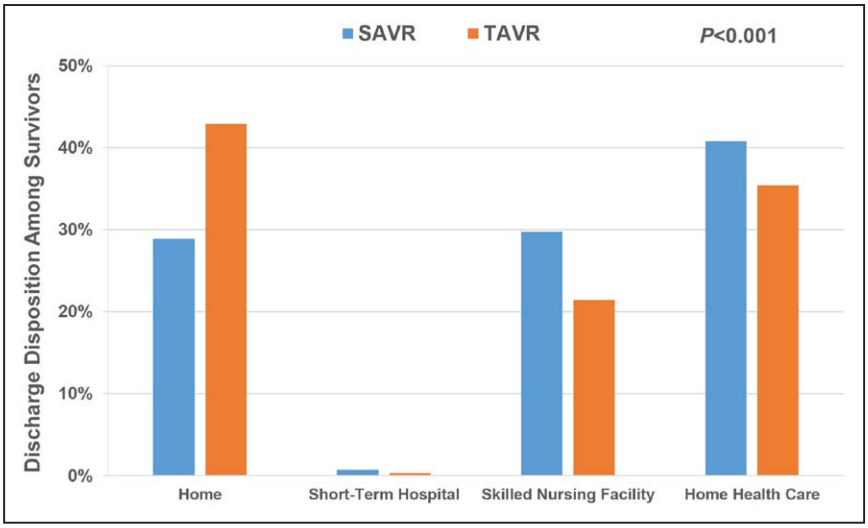


**Figure 3.** Discharge disposition among patients with prior CABG undergoing TAVR vs SAVR. *P* value reported for the comparison of discharge disposition between TAVR vs SAVR groups. SAVR indicates surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.

**Table 3. In-Hospital Outcomes of Patients With Prior CABG Undergoing Endovascular or Transapical TAVR Versus SAVR**

| | | | | EV-TAVR vs SAVR | | TA-TAVR vs SAVR | |
|---|---|---|---|---|---|---|---|
| | SAVR (n=6170) | EV-TAVR (n=7005) | TA-TAVR (n=1880) | Unadjusted OR (95% CI) | Adjusted OR* (95% CI) | Unadjusted OR (95% CI) | Adjusted OR* (95% CI) |
| In-hospital mortality | 2.5% | 1.9% | 3.2% | 0.73 (0.44–1.21) | 0.65 (0.35–1.20) | 1.28 (0.67–2.46) | 1.00 (0.47–2.16) |
| Myocardial infarction | 2.7% | 2.1% | 0.8% | 0.80 (0.49–1.28) | 0.60 (0.35–1.05) | 0.29 (0.09–0.96) | 0.20 (0.06–0.67) |
| Stroke | 2.8% | 1.4% | 2.1% | 0.50 (0.20–0.85) | 0.37 (0.19–0.71) | 0.75 (0.36–1.59) | 0.62 (0.24–1.56) |
| Bleeding complications | 24.1% | 9.9% | 16.5% | 0.34 (0.27–0.43) | 0.33 (0.25–0.43) | 0.62 (0.45–0.86) | 0.51 (0.36–0.73) |
| Vascular complications | 5.5% | 6.0% | 2.7% | 1.09 (0.80–1.50) | 1.06 (0.72–1.54) | 0.47 (0.22–1.01) | 0.32 (0.14–0.71) |
| AKI | 17.8% | 15.0% | 22.9% | 0.81 (0.66–0.99) | 0.60 (0.46–0.79) | 1.37 (1.04–1.80) | 0.94 (0.67–1.33) |
| AKI requiring dialysis | 1.1% | 0.9% | 2.9% | 0.87 (0.41–1.83) | 0.42 (0.17–1.02) | 2.82 (1.33–5.97) | 1.30 (0.49–3.39) |
| Requirement for PPM | 5.2% | 11.2% | 5.9% | 2.29 (1.72–3.05) | 1.79 (1.26–2.54) | 1.12 (0.69–1.80) | 0.91 (0.54–1.54) |
| Length of stay† | 8.7±5.9 days | 6.2±5.0 days | 7.8±4.8 days | 0.71 (0.70–0.72) | 0.67 (0.66–0.68) | 0.92 (0.90–0.94) | 0.82 (0.80–0.84) |

AKI indicates acute kidney injury; CI, confidence intervals; EV-TAVR, endovascular transcatheter aortic valve replacement; OR, odds ratios; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; SD, standard deviation; and TA-TAVR, transapical transcatheter aortic valve replacement.

*Adjusted for demographics (age, sex, race), hospital characteristics (region, bed size, teaching status), and all comorbidities listed in Table 1.

†Unadjusted and adjusted parameter estimates reported for length of stay represent the antilog of the β coefficients [exp(β)] obtained from the log-transformed linear regression models.



the comparative outcomes of TAVR versus SAVR in patients with prior CABG also largely support the increasing use of TAVR in these patients. In a single-center retrospective analysis of 80 patients with prior CABG undergoing AVR in Switzerland, TAVR was associated with similar in-hospital mortality (2.5% in each group), but numerically lower rates of major adverse cardiovascular (7.5% versus 17.5%; *P*=0.31) and cerebrovascular events (2.5% versus 7.5%; *P*=0.61) at 6 months compared with SAVR. Rates of PPM implantation and paravalvular leak were higher in the TAVR cohort.[15] In another single-center study of 255 patients with prior CABG undergoing AVR, TAVR was nonsignificantly associated with lower 30-day mortality (1.9% versus 4.1%; *P*=0.07) but similar 2-year mortality. However, postoperative morbidity and resource utilization was significantly lower in patients undergoing TAVR.[16] Similarly, an analysis of 226 patients with prior CABG in the CoreValve high-risk registry reported a trend toward lower 1-year mortality with TAVR (9.6% versus 18.1%; *P*=0.09). The SAVR group had longer intensive care unit and hospital LOS, higher incidence of AKI, major bleeding, and major adverse cardiovascular events (*P*<0.05 for all). As expected, PPM implantation and paravalvular leak were higher with TAVR.[13] On the contrary, subgroup analysis of 288 patients with prior CABG in the PARTNER high-risk cohort reported similar rates of perioperative death, stroke, and MI in the 2 groups but a trend toward greater 2-year all-cause mortality (hazard ratio 1.54; *P*=0.05) with TAVR.[12] A recent meta-analysis of the above studies that included 872 patients (423 in TAVR and 449 in SAVR groups) with prior CABG undergoing AVR reported no difference in all-cause or cardiovascular mortality at 1 year between the 2 groups.[17]

Cerebrovascular events continue to challenge both surgeons and interventionists as they are associated with significant morbidity and resource utilization. Despite technological advancements, stroke rates remain high, ranging from 2% to 5% with either TAVR or SAVR.[3–7] Among patients undergoing SAVR, stroke rates are significantly higher in patients with a history of prior CABG.[11] This is primarily because of aortic manipulation during cross clamping in the presence of extensive fibrosis, scarring, and calcification. Two prior single-center studies have reported numerically lower short-term stroke rates with TAVR in patients with prior CABG.[15,16] On the contrary, subgroup analysis of the PARTNER high-risk cohort reported higher absolute short-term stroke rates with TAVR.[12] In our study, we found TAVR to be associated with lower risk-adjusted odds of in-hospital stroke compared with SAVR in this patient population. TAVR was associated with higher rates of PPM implantation. This was an expected finding consistent with that of prior studies as TAVR is associated with greater risk of iatrogenic conduction disturbances. Other secondary outcomes also clearly favored the utilization of TAVR in this patient population. Patients undergoing TAVR had lower rates of MI, stroke, bleeding complications, and AKI compared with those undergoing SAVR. Lower rates of in-hospital complications with TAVR coupled with shorter LOS and lower utilization of skilled nursing facilities support the use of TAVR over SAVR as the preferred modality of AVR in patients with prior CABG.

## Study Limitations

Our study has certain limitations. Data represent AVR hospitalizations and not unique patients undergoing AVR. The NIS is an administrative database, and important clinical data such as echocardiographic variables, Society of Thoracic Surgeons risk score, and medication use were not available. Endovascular TAVR includes all percutaneous approaches, and we were unable to differentiate between femoral, direct aortic, subclavian, iliac, transcaval, or carotid access. We did not have information on valve type and size, procedural success, and postprocedural hemodynamics such as paravalvular leak. We could not determine the time interval between CABG and AVR, type of CABG, or presence of patent grafts at risk at the time of AVR. Certain variables, ie, age, heart failure, prior implantable cardioverter defibrillator, chronic renal failure, dementia, and hospital teaching status had significant residual bias (ASD>10%) even after propensity matching. However, additional adjustment for these variables in the propensity-matched cohort did not change the results of our analysis. In-hospital complications were identified using ICD-9-CM codes and could not be defined according to standardized criteria such as those by the Valve Academic Research Consortium-2. Data on postdischarge complications and mortality were lacking. Our analysis was restricted up through 2014 as this was the most recent NIS data available. Finally, given the observational design of our study, residual measured and unmeasured confounding may have accounted for some of our findings.

## Conclusions

In this analysis of a nationally representative cohort of ≈15 000 isolated AVR hospitalizations in patients with prior CABG in the United States from 2012 to 2014, we found that utilization of TAVR increased relative to SAVR, and TAVR is now the predominant modality of AVR in this population. TAVR was associated with similar in-hospital mortality, lower rate of in-hospital complications, shorter LOS, and lower requirement for skilled nursing services at discharge. Our findings support the increasing use of TAVR for AVR in this patient subset.

## Disclosures

Dr Bhatt discloses the following relationships: Advisory Board—Cardax, Elsevier Practice Update Cardiology, Medscape Cardiology, Regado Biosciences; Board of Directors—Boston VA Research Institute, Society of Cardiovascular Patient Care; Chair—American Heart Association Quality Oversight Committee; Data Monitoring Committees—Cleveland Clinic, Duke Clinical Research Institute, Harvard Clinical Research Institute, Mayo Clinic, Mount Sinai School of Medicine, Population Health Research Institute; Honoraria—American College of Cardiology (Senior Associate Editor, Clinical Trials and News, ACC.org), Belvoir Publications (Editor in Chief, Harvard Heart Letter), Duke Clinical Research Institute (clinical trial steering committees), Harvard Clinical Research Institute (clinical trial steering committee), HMP Communications (Editor in Chief, Journal of Invasive Cardiology), Journal of the American College of Cardiology (Guest Editor; Associate Editor), Population Health Research Institute (clinical trial steering committee), Slack Publications (Chief Medical Editor, Cardiology Today's Intervention), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees); Other—Clinical Cardiology (Deputy Editor), NCDR-ACTION Registry Steering Committee (Chair), VA CART Research and Publications Committee (Chair); Research Funding—Abbott, Amarin, Amgen, AstraZeneca, Bristol-Myers Squibb, Chiesi, Eisai, Ethicon, Forest Laboratories, Ironwood, Ischemix, Lilly, Medtronic, Pfizer, Regeneron, Roche, Sanofi Aventis, The Medicines Company; Royalties—Elsevier (Editor, Cardiovascular Intervention: A Companion to Braunwald's Heart Disease); Site Co-Investigator—Biotronik, Boston Scientific, St Jude Medical (now Abbott); Trustee—American College of Cardiology; Unfunded Research—FlowCo, Merck, PLx Pharma, Takeda. All other authors have no relationships relevant to this article to disclose.

## References


1. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP III, Fleisher LA, Jneid H, Mack MJ, McLeod CJ, O'Gara PT, Rigolin VH, Sundt TM III, Thompson A. 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation*. 2017;135:e1159–e1195. doi: 10.1161/CIR.0000000000000503.
2. Stewart BF, Siscovick D, Lind BK, Gardin JM, Gottdiener JS, Smith VE, Kitzman DW, Otto CM. Clinical factors associated with calcific aortic valve disease. Cardiovascular Health Study. *J Am Coll Cardiol*. 1997;29:630–634.
3. Leon MB, Smith CR, Mack M, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkar RR, Brown DL, Block PC, Guyton RA, Pichard AD, Bavaria JE, Herrmann HC, Douglas PS, Petersen JL, Akin JJ, Anderson WN, Wang D, Pocock S; PARTNER Trial Investigators. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med*. 2010;363:1597–1607. doi: 10.1056/NEJMoa1008232.
4. Smith CR, Leon MB, Mack MJ, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkar RR, Williams M, Dewey T, Kapadia S, Babaliaros V, Thourani VH, Corso P, Pichard AD, Bavaria JE, Herrmann HC, Akin JJ, Anderson WN, Wang D, Pocock SJ; PARTNER Trial Investigators. Transcatheter versus surgical aortic-valve replacement in high-risk patients. *N Engl J Med*. 2011;364:2187–2198. doi: 10.1056/NEJMoa1103510.
5. Adams DH, Popma JJ, Reardon MJ, Yakubov SJ, Coselli JS, Deeb GM, Gleason TG, Buchbinder M, Hermiller J Jr, Kleiman NS, Chetcuti S, Heiser J, Merhi W, Zorn G, Tadros P, Robinson N, Petrossian G, Hughes GC, Harrison JK, Conte J, Maini B, Mumtaz M, Chenoweth S, Oh JK; U.S. CoreValve Clinical Investigators. Transcatheter aortic-valve replacement with a self-expanding prosthesis. *N Engl J Med*. 2014;370:1790–1798. doi: 10.1056/NEJMoa1400590.
6. Leon MB, Smith CR, Mack MJ, Makkar RR, Svensson LG, Kodali SK, Thourani VH, Tuzcu EM, Miller DC, Herrmann HC, Doshi D, Cohen DJ, Pichard AD, Kapadia S, Dewey T, Babaliaros V, Szeto WY, Williams MR, Kereiakes D, Zajarias A, Greason KL, Whisenant BK, Hodson RW, Moses JW, Trento A, Brown DL, Fearon WF, Pibarot P, Hahn RT, Jaber WA, Anderson WN, Alu MC, Webb JG; PARTNER 2 Investigators. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. *N Engl J Med*. 2016;374:1609–1620. doi: 10.1056/NEJMoa1514616.
7. Reardon MJ, Van Mieghem NM, Popma JJ, Kleiman NS, Søndergaard L, Mumtaz M, Adams DH, Deeb GM, Maini B, Gada H, Chetcuti S, Gleason T, Heiser J, Lange R, Merhi W, Oh JK, Olsen PS, Piazza N, Williams M, Windecker S, Yakubov SJ, Grube E, Makkar R, Lee JS, Conte J, Vang E, Nguyen H, Chang Y, Mugglin AS, Serruys PW, Kappetein AP; SURTAVI Investigators. Surgical or transcatheter aortic-valve replacement in intermediate-risk patients. *N Engl J Med*. 2017;376:1321–1331. doi: 10.1056/NEJMoa1700456.
8. Lytle BW, Cosgrove DM, Taylor PC, Gill CC, Goormastic M, Golding LR, Stewart RW, Loop FD. Reoperations for valve surgery: perioperative mortality and determinants of risk for 1,000 patients, 1958-1984. *Ann Thorac Surg*. 1986;42:632–643.
9. Leontyev S, Borger MA, Davierwala P, Walther T, Lehmann S, Kempfert J, Mohr FW. Redo aortic valve surgery: early and late outcomes. *Ann Thorac Surg*. 2011;91:1120–1126. doi: 10.1016/j.athoracsur.2010.12.053.
10. Baumgartner H, Falk V, Bax JJ, De Bonis M, Hamm C, Holm PJ, Iung B, Lancellotti P, Lansac E, Rodriguez Muñoz D, Rosenhek R, Sjögren J, Tornos Mas P, Vahanian A, Walther T, Wendler O, Windecker S, Zamorano JL; ESC Scientific Document Group. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. *Eur Heart J*. 2017;38:2739–2791. doi: 10.1093/eurheartj/ehx391.
11. Reinöhl J, Kaier K, Reinecke H, Frankenstein L, Zirlik A, Zehender M, von Zur Mühlen C, Bode C, Stachon P. Transcatheter aortic valve replacement: the new standard in patients with previous coronary bypass grafting? *JACC Cardiovasc Interv*. 2016;9:2137–2143. doi: 10.1016/j.jcin.2016.07.035.
12. Greason KL, Mathew V, Suri RM, Holmes DR, Rihal CS, McAndrew T, Xu K, Mack M, Webb JG, Pichard A, Williams M, Leon MB, Svensson L, Thourani V, Smith CR. Transcatheter versus surgical aortic valve replacement in patients with prior coronary artery bypass graft operation: a PARTNER trial subgroup analysis. *Ann Thorac Surg*. 2014;98:1–7; discussion 7. doi: 10.1016/j.athoracsur.2014.02.079.
13. Conte JV, Gleason TG, Resar JR, Adams DH, Deeb GM, Popma JJ, Hughes GC, Zorn GL, Reardon MJ. Transcatheter or surgical aortic valve replacement in patients with prior coronary artery bypass grafting. *Ann Thorac Surg*. 2016;101:72–79; discussion 79. doi: 10.1016/j.athoracsur.2015.06.067.
14. Jegaden O, Lapeze J, Farhart F, de Gevigney G. Aortic valve stenosis after previous coronary bypass: transcatheter valve implantation or aortic valve replacement? *J Cardiothorac Surg*. 2012;7:47. doi: 10.1186/1749-8090-7-47.
15. Stortecky S, Brinks H, Wenaweser P, Huber C, Pilgrim T, Windecker S, Carrel T, Kadner A. Transcatheter aortic valve implantation or surgical aortic valve replacement as redo procedure after prior coronary artery

bypass grafting. *Ann Thorac Surg*. 2011;92:1324–1330; discussion 1230. doi: 10.1016/j.athoracsur.2011.05.106.
16. Nguyen TC, Babaliaros VC, Razavi SA, Kilgo PD, Devireddy CM, Leshnower BG, Mavromatis K, Guyton RA, Kanitkar M, Lerakis S, Merlino J, Chen EP, Thourani VH. Transcatheter aortic valve replacement has improved short-term but similar midterm outcomes in isolated aortic valve replacement after prior coronary artery bypass grafting. *Ann Thorac Surg*. 2014;98:1316–1324. doi: 10.1016/j.athoracsur.2014.05.081.
17. Ando T, Briasoulis A, Holmes AA, Afonso L, Schreiber T, Kondur A. Transcatheter aortic valve replacement versus surgical aortic valve replacement in patients with previous coronary artery bypass surgery: a systematic review and meta-analysis. *Int J Cardiol*. 2016;215:14–19. doi: 10.1016/j.ijcard.2016.04.033.
18. HCUP. Overview of the National (Nationwide) Inpatient Sample (NIS). http://www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed June 20, 2017.
19. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. *Med Care*. 1998;36:8–27.
20. HCUP. NIS Description of Data Elements. https://www.hcup-us.ahrq.gov/db/nation/nis/nisdde.jsp. Accessed June 20, 2017.
21. Kolte D, Khera S, Sardar MR, Gheewala N, Gupta T, Chatterjee S, Goldsweig A, Aronow WS, Fonarow GC, Bhatt DL, Greenbaum AB, Gordon PC, Sharaf B, Abbott JD. Thirty-day readmissions after transcatheter aortic valve replacement in the United States: insights from the Nationwide Readmissions Database. *Circ Cardiovasc Interv*. 2017;10:e004472. doi: 10.1161/CIRCINTERVENTIONS.116.004472.
22. Gupta T, Goel K, Kolte D, Khera S, Villablanca PA, Aronow WS, Bortnick AE, Slovut DP, Taub CC, Kizer JR, Pyo RT, Abbott JD, Fonarow GC, Rihal CS, Garcia MJ, Bhatt DL. Association of chronic kidney disease with in-hospital outcomes of transcatheter aortic valve replacement. *JACC Cardiovasc Interv*. 2017;10:2050–2060. doi: 10.1016/j.jcin.2017.07.044.
23. HCUP. NIS Related Reports. https://www.hcup-us.ahrq.gov/db/nation/nis/nisrelatedreports.jsp. Accessed June 20, 2017.
24. Khera R, Angraal S, Couch T, Welsh JW, Nallamothu BK, Girotra S, Chan PS, Krumholz HM. Adherence to methodological standards in research using the National Inpatient Sample. *JAMA*. 2017;318:2011–2018. doi: 10.1001/jama.2017.17653.
25. Mamdani M, Sykora K, Li P, Normand SL, Streiner DL, Austin PC, Rochon PA, Anderson GM. Reader's guide to critical appraisal of cohort studies: 2. Assessing potential for confounding. *BMJ*. 2005;330:960–962. doi: 10.1136/bmj.330.7497.960.
26. Goel K, Gupta T, Kolte D, Khera S, Fonarow GC, Bhatt DL, Singh M, Rihal CS. Outcomes and temporal trends of inpatient percutaneous coronary intervention at centers with and without on-site cardiac surgery in the United States. *JAMA Cardiol*. 2017;2:25–33. doi: 10.1001/jamacardio.2016.4188.
27. Odell JA, Mullany CJ, Schaff HV, Orszulak TA, Daly RC, Morris JJ. Aortic valve replacement after previous coronary artery bypass grafting. *Ann Thorac Surg*. 1996;62:1424–1430. doi: 10.1016/0003-4975(96)00635-2.
28. Byrne JG, Karavas AN, Filsoufi F, Mihaljevic T, Aklog L, Adams DH, Cohn LH, Aranki SF. Aortic valve surgery after previous coronary artery bypass grafting with functioning internal mammary artery grafts. *Ann Thorac Surg*. 2002;73:779–784.

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**Transcatheter Versus Surgical Aortic Valve Replacement in Patients With Prior Coronary Artery Bypass Grafting: Trends in Utilization and Propensity-Matched Analysis of In-Hospital Outcomes**

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**SUPPLEMENTAL MATERIAL**

**Table 1.** International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) Codes Used to Identify Study Population.

| | |
|---|---|
| **Inclusion Criteria** | |
| TAVR | 35.05 (endovascular), 35.06 (transapical) |
| SAVR | 35.21, 35.22 |
| **Exclusion Criteria** | |
| PCI | 00.66, 36.01, 36.02, 36.05, 36.06, 36.07, 17.55 |
| CABG | 36.1x |
| Aortic root replacement | 38.44, 38.45 |
| Tricuspid valve procedures | 35.14, 35.27, 35.28 |
| Pulmonic valve procedures | 35.13, 35.25, 35.26 |
| Mitral valve procedures | 35.12, 35.23, 35.24 |
| Prior valve replacement | V43.3 |

CABG = coronary artery bypass grafting; PCI = percutaneous coronary intervention; SAVR = surgical aortic valve replacement; TAVR = transcatheter aortic valve replacement.

**Table 2.** International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) and Clinical Classification Software (CCS) Codes Used to Identify Comorbidities.

| **Comorbidity** | **Code(s)** |
|---|---|
| Smoking | 30.51 |
| Dyslipidemia | 53 (CCS) |
| Known CAD | 414.00–07 |
| Prior MI | 412 |
| Prior PCI | V45.82 |
| Carotid artery disease | 433.10 |
| Prior TIA/stroke | V12.54, 438.x |
| Atrial fibrillation | 427.31 |
| Prior PPM | V45.01 |
| Prior ICD | V45.02 |
| Dementia | 290.xx, 294.1x, 294.2x, 294.8, 331.0–2, 331.82, 797 |

Heart failure, diabetes mellitus, hypertension, obesity, peripheral vascular disease, chronic renal failure, anemia, chronic pulmonary disease, coagulopathy, hypothyroidism, liver disease, fluid and electrolyte disorders, cancer, and neurological disorders were identified from the Elixhauser comorbidities included in the National Inpatient Sample database.

CAD = coronary artery disease; ICD = implantable cardioverter defibrillator; MI = myocardial infarction; PCI = percutaneous coronary intervention; PPM = permanent pacemaker; TIA = transient ischemic attack.

**Table 3.** International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) Codes Used to Identify In-Hospital Complications.

| Complication | Code(s) |
|---|---|
| MI | 410.x1, 411.1 |
| Stroke | 431, 433.x1, 434.x1, 344.6x, 997.01, 997.02 |
| Bleeding complications | 430, 431, 432.x, 336, 362.43, 362.81, 363.61, 363.62, 363.72, 364.41, 3736.32, 377.42, 379.23; 423.0 + 37.0;<br>923.x + 729.71, 924.x + 729.72, 922.2–9 + 729.73;<br>456.0, 456.20, 530.7, 530.82, 531.00, 531.01, 531.20, 531.21, 531.40, 531.41, 531.60, 531.61, 532.00, 532.01, 532.20, 532.21, 532.40, 532.41, 532.60, 532.61, 533.00, 533.01, 533.20, 533.21, 533.40, 533.41, 533.60, 533.61, 534.00, 534.01, 534.20, 534.21, 534.40, 534.41, 534.60, 534.61, 569.3, 578.0, 578.1, 578.9, 568.81, 599.70, 599.71, 719.1x, 784.7, 784.8, 459, 998.11, 998.12, 285.1<br>+ 998.00, 998.09, 785.50, 785.59, 276.52<br>+ 00.17<br>+ 99.0x |
| Vascular complications | 900–904, 998.2, 999.2, 997.7, 447.0, 868.04<br>+ 39.31, 39.41, 39.49, 39.52, 39.56, 39.57, 39.59, 39.79<br>+ 441.0, 441.00, 441.01, 441.02, 441.03, 441.1, 441.3, 441.5, 441.6, 414.10, 414.19, 414.12, 443.22, 444, 444.0, 444.01, 441.09, 444.1, 444.2, 444.21, 444.22, 444.8, 444.81, 444.89, 444.9 |
| AKI | 584.x |
| AKI requiring dialysis | 584.x+39.95 |
| PPM placement | 37.80–83, 00.50 |

AKI = acute kidney injury; MI = myocardial infarction; PPM = permanent pacemaker.

**Table 4.** Propensity-Matched Analysis of In-Hospital Outcomes of Patients with Prior CABG Undergoing TAVR Versus SAVR.

| | **SAVR** | **TAVR** | **Adjusted OR* (95% CI)** |
|---|---|---|---|
| In-hospital mortality | 2.4% | 2.3% | 0.86 (0.63-1.16) |
| Myocardial infarction | 3.4% | 1.5% | 0.43 (0.31-0.59) |
| Stroke | 2.6% | 1.4% | 0.56 (0.40-0.79) |
| Bleeding complications | 24.6% | 10.6% | 0.31 (0.28-0.36) |
| Vascular complications | 5.4% | 5.5% | 0.98 (0.80-1.20) |
| AKI | 19.3% | 16.2% | 0.66 (0.58-0.75) |
| AKI requiring dialysis | 1.2% | 1.2% | 0.81 (0.53-1.26) |
| Requirement for PPM | 5.4% | 8.9% | 1.66 (1.38-1.99) |
| Length of stay† | 9.1±6.0 days | 6.6±5.1 days | 0.70 (0.68-0.71) |

AKI indicates acute kidney injury; CI, confidence intervals; OR, odds ratios; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; SD, standard deviation; TAVR, transcatheter aortic valve replacement.

*Adjusted for age, heart failure, prior ICD, chronic renal failure, dementia, and hospital teaching status in the propensity-matched cohort.

†Adjusted parameter estimate reported for length of stay represents the antilog of the ß coefficients [exp(ß)] obtained from the log-transformed linear regression models.

**Table 5. In-Hospital Outcomes of Patients with Prior CABG Undergoing TAVR Versus SAVR.**

| | Before matching | | | After matching | | |
|---|---|---|---|---|---|---|
| | **SAVR (n=5,395)** | **TAVR (n=8,315)** | ***P* value** | **SAVR (n=3,420)** | **TAVR (n=3,420)** | ***P* value** |
| **In-hospital mortality** | | | | | | |
| % | 2.4% | 2.2% | - | 2.3% | 2.2% | - |
| Unadjusted OR (95% CI) | Ref. | 0.92 (0.57-1.50) | 0.74 | Ref. | 0.94 (0.68-1.29) | 0.69 |
| Adjusted OR* (95% CI) | Ref. | 0.71 (0.38-1.36) | 0.31 | - | - | - |
| **Myocardial infarction** | | | | | | |
| % | 2.4% | 1.9% | - | 2.9% | 0.9% | - |
| Unadjusted OR (95% CI) | Ref. | 0.77 (0.46-1.29) | 0.32 | Ref. | 0.29 (0.20-0.44) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.50 (0.27-0.94) | 0.03 | - | - | - |
| **Stroke** | | | | | | |
| % | 2.2% | 1.4% | - | 2.0% | 1.0% | - |
| Unadjusted OR (95% CI) | Ref. | 0.64 (0.36-1.14) | 0.13 | Ref. | 0.50 (0.33-0.75) | 0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.43 (0.21-0.88) | 0.02 | - | - | - |
| **Bleeding complications** | | | | | | |
| % | 22.7% | 11.4% | - | 22.1% | 11.7% | - |
| Unadjusted OR (95% CI) | Ref. | 0.44 (0.35-0.55) | <0.001 | Ref. | 0.47 (0.41-0.53) | <0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.42 (0.32-0.55) | <0.001 | - | - | - |
| **Vascular complications** | | | | | | |
| % | 4.9% | 5.5% | - | 4.8% | 4.5% | - |
| Unadjusted OR (95% CI) | Ref. | 1.13 (0.81-1.59) | 0.46 | Ref. | 0.94 (0.75-1.17) | 0.57 |
| Adjusted OR* (95% CI) | Ref. | 0.94 (0.63-1.39) | 0.76 | - | - | - |
| **AKI** | | | | | | |
| % | 16.8% | 17.0% | - | 18.6% | 15.5% | - |
| Unadjusted OR (95% CI) | Ref. | 1.01 (0.83-1.24) | 0.90 | Ref. | 0.80 (0.71-0.91) | 0.001 |
| Adjusted OR* (95% CI) | Ref. | 0.73 (0.55-0.97) | 0.03 | - | - | - |
| **AKI requiring dialysis** | | | | | | |
| % | 0.9% | 1.3% | - | 1.0% | 1.2% | - |
| Unadjusted OR (95% CI) | Ref. | 1.37 (0.64-2.92) | 0.42 | Ref. | 1.15 (0.73-1.81) | 0.56 |
| Adjusted OR* (95% CI) | Ref. | 0.71 (0.30-1.71) | 0.45 | - | - | - |
| **Requirement for PPM** | | | | | | |
| % | 4.4% | 10.2% | - | 4.5% | 10.7% | - |
| Unadjusted OR (95% CI) | Ref. | 2.45 (1.77-3.38) | <0.001 | Ref. | 2.52 (2.07-3.06) | <0.001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Adjusted OR* (95% CI) | Ref. | 1.89 (1.28-2.80) | 0.001 | - | - | - |
| **Length of stay**† | | | | | | |
| Mean±SD, days | 8.3±5.2 | 6.5±5.0 | - | 8.6±5.3 | 6.3±5.0 | - |
| Unadjusted parameter estimate (95% CI) | Ref. | 0.78 (0.76-0.79) | <0.001 | Ref. | 0.73 (0.71-0.75) | <0.001 |
| Adjusted parameter estimate* (95% CI) | Ref. | 0.72 (0.71-0.73) | <0.001 | - | - | - |

*Hospitalizations with a concomitant primary or secondary diagnosis of aortic stenosis (ICD-9-CM codes 395.0, 395.2, 396.2, 424.1, and 746.3) were selected for this sensitivity analysis.*

AKI indicates acute kidney injury; CI, confidence intervals; OR, odds ratios; PPM, permanent pacemaker; TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement; SD, standard deviation.

*Adjusted for demographics (age, sex, race), hospital characteristics (region, bed size, teaching status), and all comorbidities listed in Table 1.

†Unadjusted and adjusted parameter estimates reported for length of stay represent the antilog of the ß coefficients [exp(ß)] obtained from the log-transformed linear regression models.

**Table 6.** Propensity-Matched Analysis of In-Hospital Outcomes of Patients with Prior CABG Undergoing Endovascular TAVR Versus SAVR.

| | **SAVR (n=3,515)** | **TAVR (n=3,515)** | **Adjusted OR (95% CI)** |
|---|---|---|---|
| In-hospital mortality | 2.1% | 1.8% | 0.86 (0.62-1.21) |
| Myocardial infarction | 3.1% | 1.8% | 0.58 (0.43-0.80) |
| Stroke | 2.1% | 1.4% | 0.66 (0.46-0.95) |
| Bleeding complications | 23.8% | 9.4% | 0.33 (0.29-0.38) |
| Vascular complications | 5.0% | 5.3% | 1.06 (0.86-1.31) |
| AKI | 19.5% | 13.7% | 0.65 (0.58-0.74) |
| AKI requiring dialysis | 1.1% | 0.9% | 0.75 (0.47-1.20) |
| Requirement for PPM | 5.4% | 11.0% | 2.15 (1.78-2.58) |
| Length of stay[*] | 9.1±6.1 days | 6.3±5.2 days | 0.69 (0.68-0.71) |

AKI indicates acute kidney injury; CI, confidence intervals; OR, odds ratios; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; SD, standard deviation; TAVR, transcatheter aortic valve replacement.

[*]Adjusted parameter estimate reported for length of stay represents the antilog of the ß coefficients [exp(ß)] obtained from the log-transformed linear regression models.

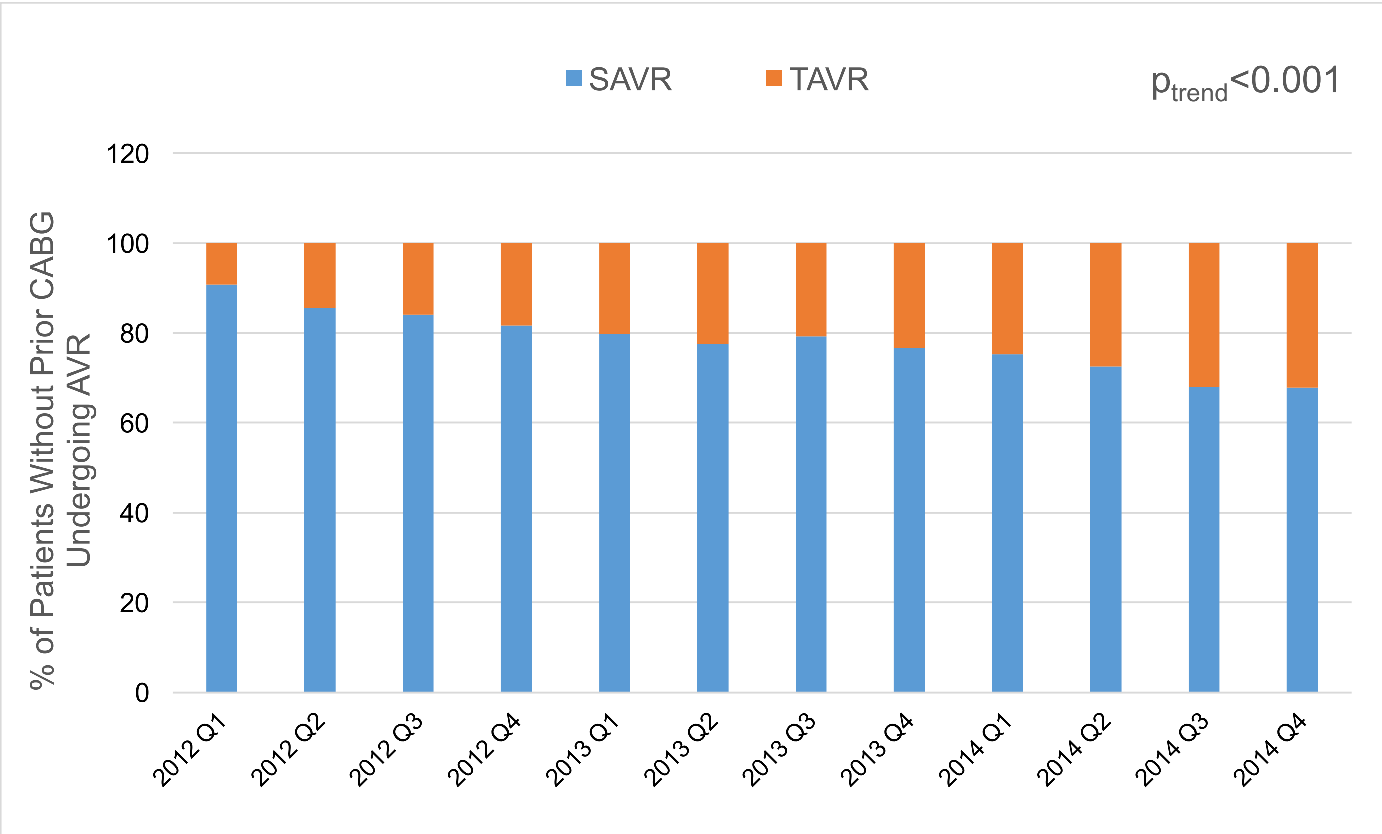
**Table 7.** Propensity-Matched Analysis of In-Hospital Outcomes of Patients with Prior CABG Undergoing Transapical TAVR Versus SAVR.

| | **SAVR (n=1,460)** | **TAVR (n=1,460)** | **Adjusted OR (95% CI)** |
|---|---|---|---|
| In-hospital mortality | 3.1% | 2.4% | 0.77 (0.49-1.21) |
| Myocardial infarction | 3.4% | 0.7% | 0.19 (0.10-0.39) |
| Stroke | 2.7% | 1.7% | 0.62 (0.37-1.03) |
| Bleeding complications | 26.0% | 18.5% | 0.65 (0.54-0.77) |
| Vascular complications | 6.8% | 2.7% | 0.38 (0.26-0.56) |
| AKI | 18.8% | 22.9% | 1.28 (1.07-1.54) |
| AKI requiring dialysis | 1.4% | 3.1% | 2.29 (1.35-3.90) |
| Requirement for PPM | 5.1% | 6.2% | 1.21 (0.89-1.66) |
| Length of stay* | 9.5±6.3 days | 7.7±5.0 days | 0.85 (0.82-0.88) |

AKI indicates acute kidney injury; CI, confidence intervals; OR, odds ratios; PPM, permanent pacemaker; SAVR, surgical aortic valve replacement; SD, standard deviation; TAVR, transcatheter aortic valve replacement.

*Adjusted parameter estimate reported for length of stay represents the antilog of the ß coefficients [exp(ß)] obtained from the log-transformed linear regression models.

**Figure 1.** Temporal Trends in Utilization of TAVR and SAVR in Patients without Prior CABG.




CABG = coronary artery bypass grafting; SAVR = surgical aortic valve replacement; TAVR = transcatheter aortic valve replacement.