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Use and outcomes of cerebral embolic protection for transcatheter aortic valve replacement: A US nationwide study

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Abstract

Background: Outcomes data on the use of cerebral embolic protection devices (CPDs) with transcatheter aortic valve replacement (TAVR) remain limited. Previous randomized trials were underpowered for primary outcomes of stroke prevention and mortality.

Methods: The National Inpatient Sample and Nationwide Readmissions Database were queried from 2017 to 2018 to study utilization and inpatient mortality, neurological complications (ischemic stroke, hemorrhagic stroke, and transient ischemic attack), procedural complications, resource utilization, and 30-day readmissions with and without use of CPD. A 1:3 ratio propensity score matched model was created.

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CONFLICT OF INTEREST

The authors declare there is no potential conflict of interest.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

Results: Among 108,315 weighted encounters, CPD was used in 4380 patients (4.0%). Adjusted mortality was lower in patients undergoing TAVR with CPD (1.3% vs. 0.5%, $p < 0.01$). Neurological complications (2.5% vs. 1.7%, $p < 0.01$), hemorrhagic stroke (0.2% vs. 0%, $p < 0.01$) and ischemic stroke (2.2% vs. 1.4%, $p < 0.01$) were also lower in TAVR with CPD. Multiple logistic regression showed CPD use was associated with lower adjusted mortality (odds ratio (OR], 0.34 [95% confidence interval [CI], 0.22–0.52), $p < 0.01$) and lower adjusted neurological complications (OR, 0.68 (95% CI, 0.54–0.85], $p < 0.01$). On adjusted analysis, 30-day all-cause readmissions (Hazard ratio, HR 0.839, [95% CI, 0.773–0.911], $p < 0.01$) and stroke (HR, 0.727 [95% CI, 0.554–0.955), $p = 0.02$) were less likely in TAVR with CPD.

Conclusion: We report real-world data on utilization and in-hospital outcomes of CPD use in TAVR. CPD use is associated with lower inpatient mortality, neurological, and clinical complications as compared to TAVR without CPD.

Keywords

aortic valve disease; embolic protection devices; percutaneous valve therapy; percutaneous intervention; transcatheter valve implantation

1 | INTRODUCTION

Transcatheter aortic valve replacement (TAVR) has emerged as a treatment of choice for symptomatic aortic stenosis across the spectrum of surgical risk.[1,2] However, cerebrovascular events remain the most dreaded peri-TAVR complication.[3,4] The stroke risk associated with TAVR ranges between 2% and 5%, with the low surgical risk TAVR trials demonstrating even lower rates of stroke at <1%.[5,2]

However, it has been reported that more than 90% of peri-TAVR ischemic brain lesions are clinically silent as determined by transcranial Doppler and diffusion-weighted MRI studies.[3,6–8] Histopathology studies of particulate debris captured by embolic protection devices have found calcium, valve tissue, arterial wall, and thrombus.[5,9] The embolic burden appears to increase with increasing aortic valve calcification, bicuspid valves, specific procedural characteristics like balloon postdilation, and type of transcatheter valve (self-expanding valve more than balloon-expandable).[10,11] Cerebral protection devices (CPDs) have been developed to decrease the cerebral embolic burden by trapping the debris. In December 2017, the Sentinel Cerebral Protection System became the only CPD approved by the Food and Drug Administration for use in the United States (US).[12] Previous randomized controlled trials of CPDs have been vastly underpowered for outcomes of stroke and mortality.[13–15] Large-scale data on the safety and efficacy of CPD with TAVR remains limited to few meta-analyses and retrospective studies that have reported conflicting results.[16,17] National Cardiovascular Data Registry-Transcatheter Valve Therapy (TVT) Registry annual report shows low utilization of CPD at around 6.9%(4136) in 2018 and 9.4%(7741) in 2019.[18]

Therefore, our study aims to investigate utilization, outcomes, and cost of care among real-world patients undergoing TAVR with CPDs using the National Inpatient Sample (NIS) and Nationwide Readmissions Database (NRD).

2 | METHODS

2.1. | Study data

The NIS is a database developed through a Federal-State-Industry partnership managed by the Agency for Healthcare Research and Quality (AHRQ). The NIS is derived from 27 state databases to create a national database for healthcare utilization, outcomes, and costs. It contains over 8 million admission records and represents a 20% sample of all participating hospitals' admissions. The NIS is compiled annually, which allows the data to be used for analysis of disease trends over time.[19] For readmissions analysis, the NRD was used. NRD captures readmission during each calendar year independently. Each patient has unique identifier code, which allows for tracing readmissions within each year. This unique identifier is randomly generated for patient privacy. Readmissions cannot be traced between years. The readmission time is calculated using the NRD days to event variable. NRD includes clinical variables suitable for readmission analysis. Institutional Review Board approval and informed consents were not required for this study given the de-identified nature of the database and its public availability.

2.2 | Study design and data selection

We analyzed International Classification of Diseases, 10th Revision Clinical Modifications (ICD-10-CM) administrative claims data. Patients undergoing TAVR (ICD-10-CM of 02RF3x) were selected.[20] CPD device use was identified using ICD-10-CM of X2A5312. NIS discharge weights were used for analysis to provide nationally-representative statistics. A flow chart of study cohort derivation is shown in Figure 1. Costs of care were the estimated total expense in US $ incurred for hospital services provided. In the NIS database, hospital charges are provided. To further calculate actual cost, the HCUP (Healthcare Cost and Utilization Project) provides Cost-to-Charge Ratio (CCR) files to estimate the cost of resource use per inpatient hospital stay. In addition to using CCR files, estimated cost was also adjusted for inflation to January 2020 US $.

Index admissions were defined for patients undergoing TAVR and discharged alive with no missing variables critical for identifying readmissions (length of stay, mortality, or days to event variables). Index admissions were identified from January to November; December was excluded to allow for 30 days readmission data.

2.3 | Outcomes

The primary outcomes of interest were in-hospital mortality and the incidence of neurological complications, defined as a composite of hemorrhagic stroke, ischemic stroke, and transient ischemic attack. Secondary outcomes were trends and resource utilization associated with CPD in patients undergoing TAVR.

2.4 | Data analysis

To account for selection bias and heterogeneity in the baseline characteristics of patients undergoing TAVR with and without CPD, a propensity score-matching model was developed using logistic regression to derive two matched cohorts. Given a much larger TAVR without CPD cohort, a 1:3 ratio, propensity-matching model was made using a caliper width of

SD 0.2 (Appendix, Figure S1). We performed propensity matching using R "MatchIt" and "cobalt" package. To reduce the bias of unweighted estimators, we applied inverse probability weights. The weights were calculated using a formula for inverse probability weighting. For the treated units weight is 1 and for the control units weights are calculated using p/(1-p). The control unit is weighted as the total sum of the inverse of the control united matched across the sample[21,22] (Figure S1). Categorical variables were presented as frequencies and percentages, and continuous variables were reported as medians with interquartile range. Baseline characteristics were compared using Pearson $\chi 2$ and Fisher's exact tests for categorical variables and Mann–Whitney U test for continuous variables. Multiple logistic regression analyses were performed for predictors of in-patient mortality using relevant demographic and clinical variables. For all analyses, a two-tailed p value of 0.05 was considered statistically significant.

For the NRD readmission analysis, Cox regression anaylsis was used to determine CPD association with 30-day all-cause and stroke readmissions. Age, sex, median income, coronary artery disease, prior stroke history, and 28 standard co-morbidities were used for adjusted analysis. Statistical analyses were performed using the Statistical Package for Social Science version 26 (IBM Corp) and the R Project for Statistical Computing V3.5.

3 | RESULTS

Between January 2017 and December 2018, 108,315 patients who underwent TAVR were identified including 4380 (4.0%) patients with CPD utilization. The TAVR without CPD and with CPD cohorts were comparable in terms of age (79.4 years [*SD* 8.5] vs. 79.4 year. [*SD* 8.1], p = 0.84) and sex distribution (female 46.4% vs. 45.0%, p = 0.07). Patients undergoing TAVR with CPD were more likely to be Caucasian that patients undergoing TAVR without CPD (87% vs. 84%, p < 0.01). The detailed baseline characteristics are summarized in Table 1. Over the study period, the proportion of CPD use increased from 1% (535) in 2017 to 6.7% (3845) in 2018 (Figure 2).

3.1 | Clinical outcomes in propensity matched cohort

Compared to TAVR without CPD, adjusted mortality was lower in patients undergoing TAVR with CPD (1.3% vs. 0.5%, p < 0.01). Composite neurologic complications (2.5% vs. 1.7%, p < 0.01), hemorrhagic stroke (0.2% vs. 0%, p < 0.01) and ischemic stroke (2.2% vs. 1.4%, p < 0.01) were lower in TAVR with CPD compared to TAVR without CPD. Procedural complications were significantly higher in patients undergoing TAVR without CPD, including major bleeding (1.2% vs. 0.6%, p < 0.01), acute kidney injury (10.8% vs. 8.1%, p < 0.01) and respiratory complications (5.9% vs. 3.9%, p < 0.01) (Figure 3). A higher percentage of patients were discharged to home postTAVR with CPD (71.8%) as compared to patients undergoing TAVR without CPD (64.1%, p < 0.01) (Table 2).

3.2 | Temporal trends

Mortality in the TAVR with CPD group increased from 0% in 2017 to 0.5% in 2018 (Figure 4A). The mean length of stay was marginally shorter, (3.8 days to 3.5 days; p < 0.01)

(Figure 4B) and the cost of care was lower in 2018 compared to 2017 in the TAVR with CPD group ($55,719 to $50,985; p < 0.01) (Figure 4C).

3.3 | Predictors of mortality and neurological complications

Multiple logistic regression showed CPD use was associated with lower adjusted mortality (odds ratio (OR], 0.34 [95% confidence interval [CI], 0.22–0.52], p < 0.01) (Figure 5A). TAVR with CPD was also associated with lower adjusted neurological complications (OR, 0.68 [95% CI, 0.54–0.85], p < 0.01). Prior history of stroke was predictor of neurological complications (OR, 1.24 [95% CI, 1.21–1.38], p < 0.01) (Figure 5B).

3.4 | Readmissions database analysis

During 2017, 27,698 index admissions were identified, of which 27,463 had TAVR without CPD and 235(0.8%) had TAVR with CPD. 30-days readmissions were 14.1% (3893) and 17.0% (40) respectively (Table S1). In 2018, 31,253 index admissions were identified, of which 29,379 had TAVR without CPD and 1874 (6.0%) had TAVR with CPD. Thirty days readmissions were 14.1% (4147) and 11.4% (215), respectively. Adjusted analysis showed that 30-day readmissions (Hazard ratio, HR 0.839, [95% CI, 0.773–0.911], p < 0.01) and stroke (HR, 0.727[95% CI, 0.554–0.955], p = 0.02) were less likely in TAVR with CPD (Table 3).

4 | DISCUSSION

We report the following major findings from our contemporary real-world study of outcomes with and without the use of CPD during TAVR. (1) Use of CPD with TAVR was associated with lower rates of in-hospital neurologic complications, ischemic strokes, and procedural complications such as acute kidney injury, respiratory complications, and major bleeding. (2) CPD utilization with TAVR showed an upward trend, however, utilization of CPD remained very low.

The data on the efficacy of CPD to decrease the incidence of periprocedural stroke postTAVR has shown conflicting results. Despite the lower incidence of stroke with improved TAVR valve design, operator experience, and lower risk patients, cerebral vascular events remain a source of significant mortality and morbidity.[23] TAVR procedures release debris from the aortic valve, leading to perfusion deficits in the brain detected on MRI.[9] Previous studies have shown that debris is captured in up to 99% of patients undergoing TAVR with CPD[7,4] and 80% of nonCPD TAVR patients have subclinical cerebral embolic lesions.[13,24]

We report a significant decrease in neurologic complications and ischemic stroke in the TAVR with CPD group. The SENTINEL (Protection Against Cerebral Embolism During TAVR) trial was the first trial that evaluated major adverse cardiac and cerebrovascular events and MRI-assessed new lesion volume as a primary endpoints and did not show a significant difference in the incidence of stroke in the CPD arm compared to control (5.6% vs. 9.1%, p = 0.25).[13] A meta-analysis by Bagur et al. also did not show a significant decrease in stroke risk with CPD use in TAVR.[16] However, a subsequent, larger meta-analysis by Testa et al. reported a statistically significant decrease in stroke rates

with CPD use.[25] The results of this latter meta-analysis were largely driven by a large propensity-matched study by Seeger et al. that led to reporting of a significant decrease in stroke risk, although no difference in stroke rate was observed when only randomized controlled trials (RCT) were included.[17] Overall, the meta-analyses performed to date suffer from low quality of evidence due to inclusion of data from nonrandomized studies and usage of multiple CPDs. Furthermore, all major RCTs including CLaret Embolic Protection ANd TAVI,[14] MISTRAL-C (Filter-based cerebral embolic protection with transcatheter aortic valve implantation),[15] and SENTINEL[13] were underpowered to detect a statistically significant difference in stroke, likely due to low incidence of stroke in both arms. Our findings contrast with a recent analysis of nationwide TAVR data from Germany that demonstrated no difference in stroke or delirium in with CPD compared to the no CPD.[26] However, our findings are particularly robust due to our identification of the largest sample size of patients in the TAVR with CPD cohort to date. In addition, we report significantly improved periprocedural morbidity with CPD group having lower rates of AKI, vascular complications, and major bleeding. The reasons behind lower nonneurological complications in CPD group are not known but we hypothesize that these could be due to lower incidence of severe neurological complications, which in turn would result in lower incidence of mechanical ventilation, AKI and multiorgan failure. AKI is a perioperative complication seen in up to 20% of patients undergoing TAVR and is associated with multi-fold increase risk of in-hospital mortality.[27,28] Furthermore, major bleeding requiring transfusion was higher in the TAVR with no CPD group. This reduction in both major bleeding and AKI likely helped drive lower mortality in the CPD group.[29]

The utilization of CPD with TAVR remains very low, despite the pathophysiologic basis for periprocedural stroke being largely embolic, the mechanistic plausibility that collecting the embolic debris with CPD will result in lower clinical strokes and multiple studies suggesting protection against periprocedural stroke with CPD use.[16,17] The utilization of CPD remains low outside of the US as well. A recent analysis of the German nationwide database reported CPD utilization rates of 3.8% in TAVR.[26] Institutional availability of the device, learning curve, need for additional radial arterial access, poor procedural reimbursement, and equivocal benefit in underpowered RCTs may be reasons for underutilization. Our study included the last quarter of 2018, during which the use of Sentinel device was approved for additional reimbursement by the Centers for Medicare and Medicaid Services, which may have helped facilitate increased usage. Furthermore, data from TVT registry shows similar rates of utilization of CPD(6.7% in this study as compared to 6.9% in registry data for the year 2018).[18]

Low CPD utilization may also be associated with the changing demographics of TAVR patients. The mean age of the patients undergoing TAVR has drifted lower over the years: while stroke risk may be lower, a disabling stroke can significantly impact productivity and quality of life. Further understanding of risk factors for periprocedural stroke and a validated risk score could help select patients who may benefit most from CPD. The results of the on-going PROTECTED TAVR (Stroke PROTECTion With SEntinel During TAVR, NCT04149535) trial may provide the much-needed RCT evidence for a more definitive judgment on the role of CPD in TAVR.[30] This trial uses the Sentinel device and is currently enrolling 3000 patients to evaluate the endpoint of neurologist-adjudicated

clinical stroke. A strategy of routine CPD use compared to selective use in those at high risk for periprocedural stroke remains to be studied in terms of cost-effectiveness. Intriguingly, despite the lower stroke risk, shorter length of stay, and lower periprocedural morbidity, cost of stay for CPD was higher in our unadjusted analysis. A similar finding of increased cost of hospitalization was also reported by Megaly et al. and could be related to the cost of the device.[31] It is likely that device technology will continue to evolve to address the limitations of current generation device, specifically Sentinel's lack of protection of the left vertebral artery and the vascular anatomic limitations that preclude utilization in 10% of patients.

Lastly, we also noticed lower mortality in this study in both adjusted and unadjusted analysis. The mortality benefit associated with the use of CPD, and Sentinel CPS in particular, has been a subject of debate.[16,17] Two nonrandomized studies including a large propensity-matched study by Seeger et al.[17] also showed no difference in mortality.[25] A previous, more limited NIS analysis by Megaly et al. reported data from 525 weighted hospitalizations with CPD and reported zero mortality compared to 1.4% mortality among 35,695 hospitalizations with TAVR without CPD use ($p < 0.001$). However, the results may have been affected by the small sample size of the CPD group, low rate of events, and selection bias.[31] The reasons for the decreased mortality could not be ascertained in our study, and further studies are needed to confirm this finding. However, we hypothesize that decreased stroke risk and decreased perioperative comorbidity may have led to lower mortality in the TAVR with CPD group.

4.1 | Limitations

Our study is constrained by the inherent limitations of the NIS and NRD. NIS and NRD are administrative claims databases that use ICD-10-CM codes, which may be subject to error. However, the large scale of the databases may compensate for this bias. NIS collects data on in-patient discharges, and each admission is registered as an independent event. NIS samples are not designed to follow patients longitudinally, so long-term outcomes could not be assessed from the present dataset. Like any retrospective database study, association does not mean causation, and conclusions should be drawn cautiously. In administrative databases, neurologic imaging, severity of stroke (disabling vs. nondisabling), territory of stroke, and procedural success both for CPD and TAVR could not be evaluated. The type of TAVR device used was also not available. Potential bias also include difference in operator and center's skill. Like any retrospective study, results should be interpreted with caution. Unmeasured confounders could have affected our observations and highlight the need for adequately powered RCTs. In addition, NRD only captures readmissions within a calendar year, and patients not readmitted are not followed.

5 | CONCLUSION

We report real-world data on in-hospital outcomes of CPD use in TAVR. CPD use in TAVR was associated with significantly lower neurologic complications, and procedural complications compared with nonCPD TAVR. Overall, the utilization of CPD with TAVR remains low. Large, randomized trials are needed to establish the efficacy and cost-

effectiveness of CPD to reduce neurologic complications and mortality associated with TAVR.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

DATA AVAILABILITY STATEMENT

Data will be made available on request.

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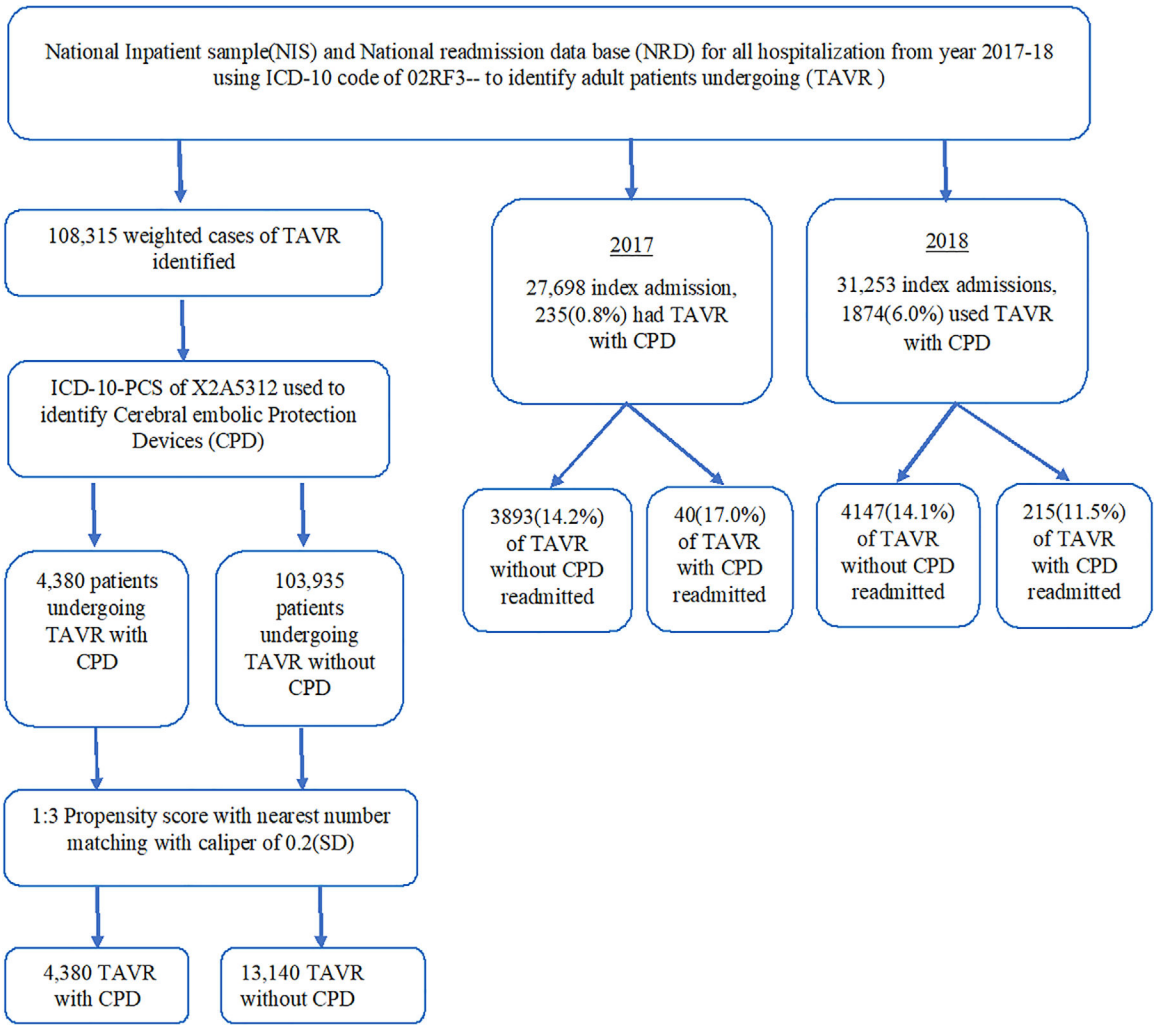

FIGURE 1.
Flow sheet representing study plan [Color figure can be viewed at wileyonlinelibrary.com]

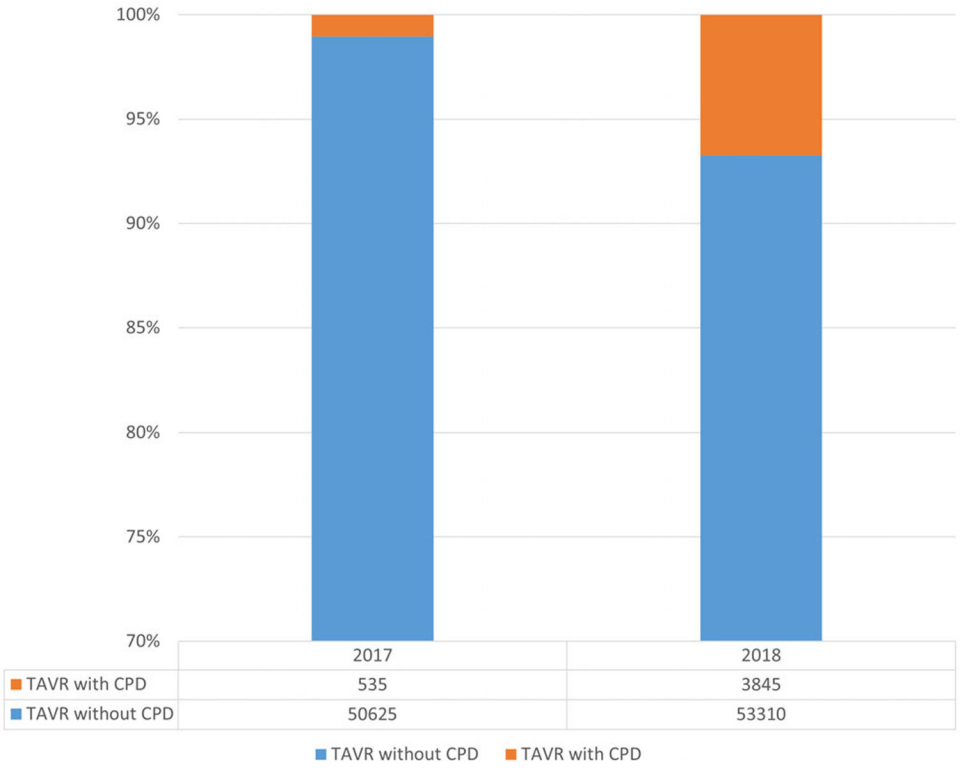

FIGURE 2.

Trends in proportion of patients undergoing TAVR with and without CPD. CPD, cerebral protection devices; TAVR, transcatheter aortic valve replacement [Color figure can be viewed at wileyonlinelibrary.com]

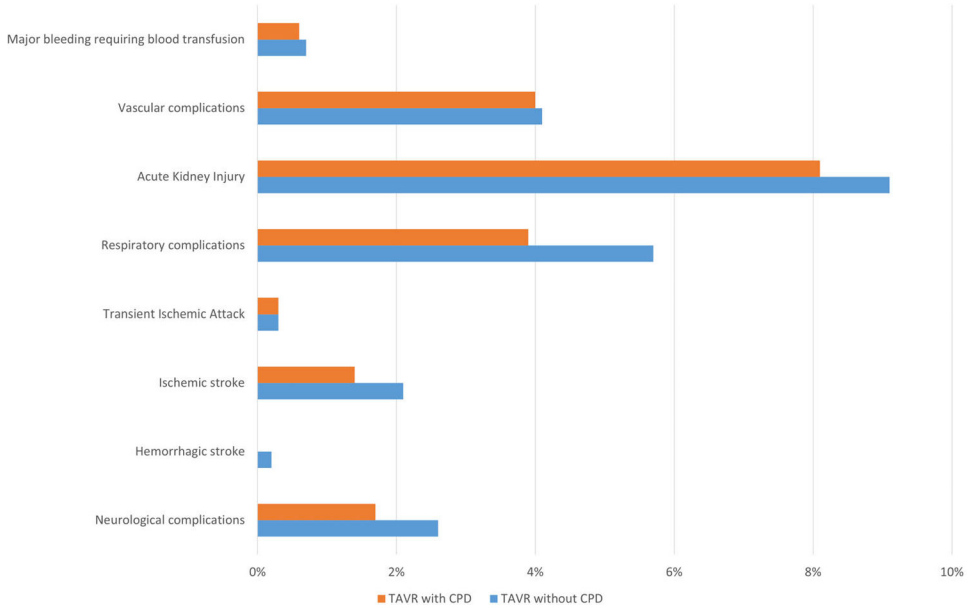

FIGURE 3.

Complications in patients undergoing TAVR with and without CPD in adjusted cohort. CPD, cerebral protection devices; TAVR, transcatheter aortic valve replacement [Color figure can be viewed at wileyonlinelibrary.com]

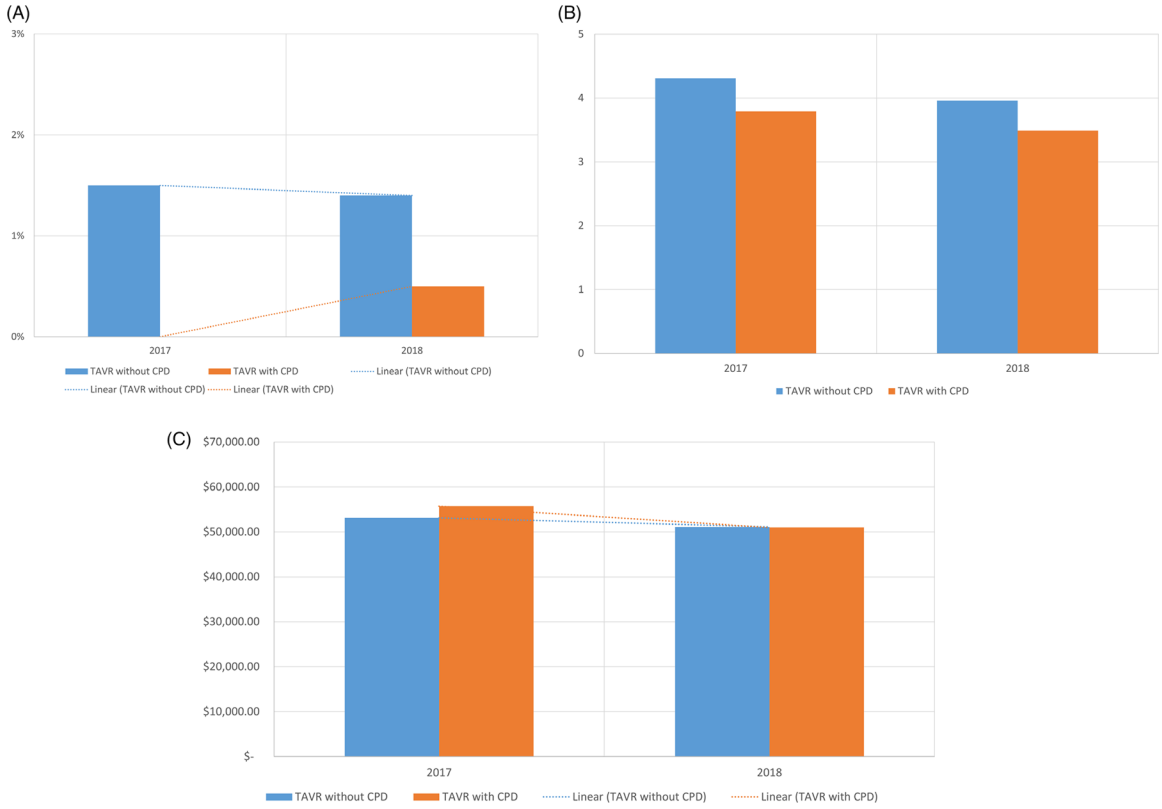

FIGURE 4.

A, Trends in mortality in patients undergoing TAVR with and without CPD. B, Trends in cost of stay in patients undergoing TAVR with and without CPD. C, Trends in the length of stay in patients undergoing TAVR with and without CPD. CPD, cerebral protection devices; TAVR, transcatheter aortic valve replacement [Color figure can be viewed at wileyonlinelibrary.com]

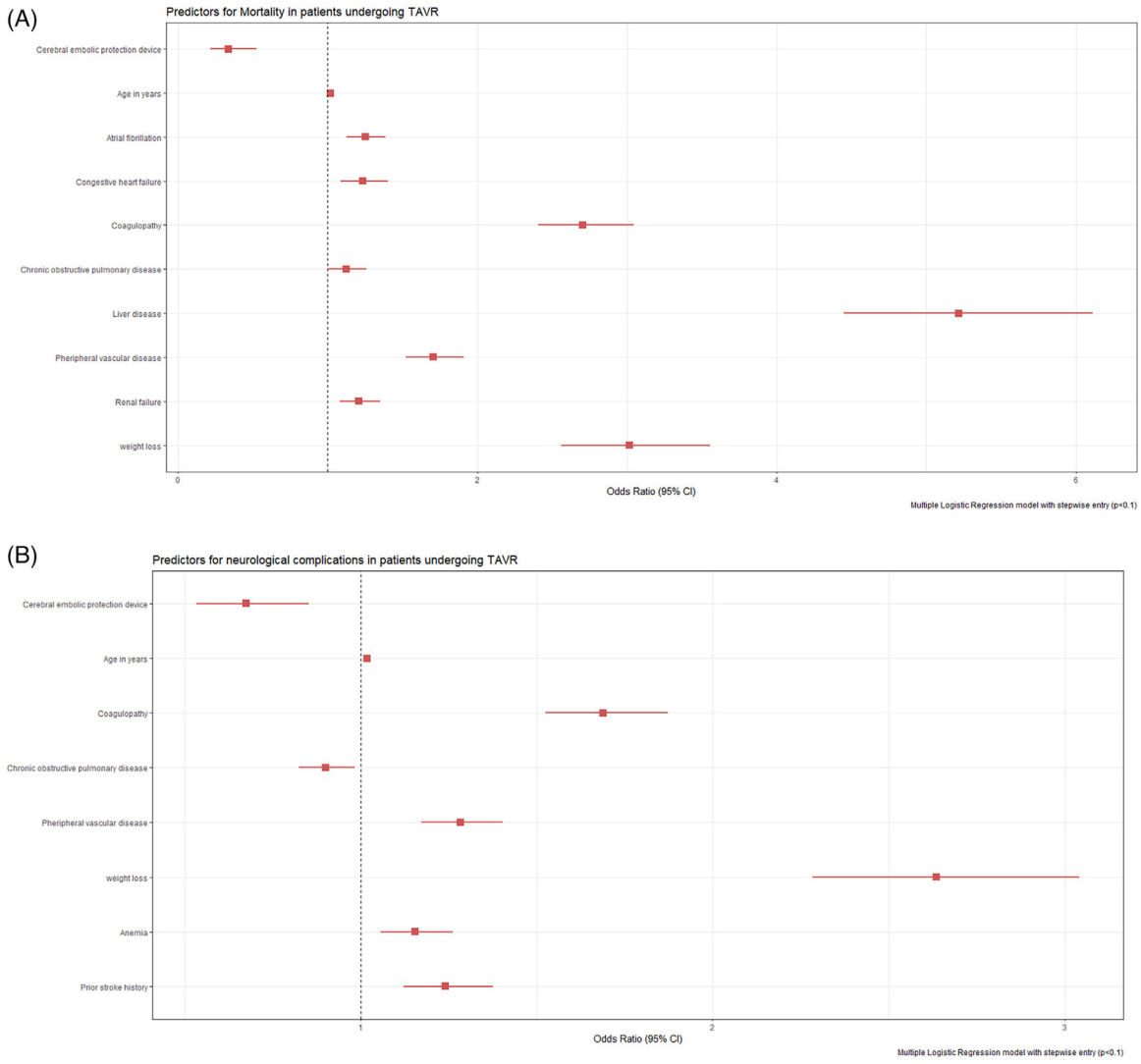

FIGURE 5.

A, Predictors of mortality in patients undergoing TAVR with and without CPD. B, Predictors of neurological complications in patients undergoing TAVR with and without CPD. CPD, cerebral protection devices; TAVR, transcatheter aortic valve replacement [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1

Baseline characteristics of patients undergoing TAVR with and without CPD (2017–2018)

	Unmatched			Matched (1:3 Propensity match)		
Variable *n* (%)	**TAVR without CPD (103,935)**	**TAVR with CPD (4380)**	**p value**	**TAVR without CPD (13,140)**	**TAVR with CPD (4380)**	***SD***
Age median (*SD*)	81(75–86)	81(74–87)	0.25	82(75–87)	81(74–87)	−0.138
Female	48,185(46.4)	1970(45.0)	0.07	6150(46.8)	1970(45)	−0.058
Race						
White	87,335(84.0)	3810(87.0)	<0.01	11,515(87.6)	3810(87.0)	0.007
African American	4225(4.1)	115(2.6)		400(3.0)	115(2.6)	
Hispanic	5255(5.1)	155(3.5)		560(4.3)	155(3.5)	
Other	7120(6.9)	300(6.8)		665(5.1)	300(6.8)	
Comorbidities and previous medical history						
Anemias	23,740(22.8)	1015(23.2)	0.61	420(3.2)	155(3.5)	−0.016
Atrial fibrillation	41,335(39.8)	1775(40.5)	0.32	5255(40.0)	1775(40.5)	−0.012
Congestive heart failure	76,145(73.3)	3255(74.3)	0.12	9775(74.4)	3255(74.3)	0.029
Coagulopathy	11,495(11.1)	340(7.8)	<0.01	945(7.2)	340(7.8)	0.118
Chronic pulmonary disease	29,655(28.5)	1035(23.6)	<0.01	2900(22.1)	1035(23.6)	0.050
Coronary artery disease	71,260(68.6)	2965(67.7)	0.23	8875(67.5)	2965(67.7)	0.025
Prior Cerebrovascular disease	15,145(14.6)	645(14.7)	0.78	1840(14.0)	645(14.7)	−0.058
Prosthetic valve history	1970(1.9)	75(1.7)	0.38	140(1.1)	75(1.7)	0.083
Diabetes	15,805(15.2)	620(14.2)	0.06	1745(13.3)	620(14.2)	0.018
Hypertension	93,780(90.2)	3885(88.7)	<0.01	11,815(89.9)	3885(88.7)	−0.026
Liver disease	3245(3.1)	150(3.4)	0.26	345(2.6)	150(3.4)	0.070
Obesity	20,630(19.8)	750(17.1)	<0.01	2220(16.9)	750(17.1)	0.049
Peripheral vascular disease	21,420(20.6)	620(14.2)	<0.01	1875(14.3)	620(14.2)	0.052
Pulmonary Hypertension	17,835(17.2)	750(17.1)	0.95	2080(15.8)	750(17.1)	0.049
Renal failure	36,870(35.5)	1455(33.2)	<0.01	4230(32.2)	1455(33.2)	−0.012
Weight loss	3245(3.1)	125(2.9)	0.32	265(2.0)	125(2.9)	0.097
Urban/rural						
Rural	940(0.9)	25(0.6)	<0.01	50(0.4)	25(0.6)	0.019
Urban, nonteaching	9825(9.5)	25(0.6)		180(1.4)	25(0.6)	
Urban, teaching	93,170(89.6)	4330(98.9)		12,910(98.2)	4330(98.9)	
Hospital size						
Small	7495(7.2)	55(1.3)	<0.01	205(1.6)	55(1.3)	0.019
Medium	21,230(20.4)	550(12.6)		1600(12.2)	550(12.6)	
large	75,210(72.4)	3775(86.2)		11,335(86.3)	3775(86.2)	
Primary payer						
Medicare	92,590(89.5)	39,909(91.1)	<0.01	12,155(92.5)	3990(91.1)	0.068
Medicaid	1430(1.4)	40(0.9)		180(1.4)	40(0.9)	
Private insurance	7430(7.2)	270(6.2)		685(5.2)	270(6.2)	
Self-pay	375(0.4)	25(0.6)		20(0.2)	25(0.6)	

	Unmatched			Matched (1:3 Propensity match)		
Variable *n* (%)	**TAVR without CPD (103,935)**	**TAVR with CPD (4380)**	**p value**	**TAVR without CPD (13,140)**	**TAVR with CPD (4380)**	***SD***
Other	1680(1.6)	55(1.3)		100(0.8)	55(1.3)	

Abbreviations: CPD, cerebral embolic protection device; TAVR; transcatheter aortic valve replacement.

TABLE 2

Clinical outcomes and resource utilization in the unadjusted and propensity-matched cohorts in the transcatheter aortic valve replacement (TAVR) procedure performed without and with cerebral protection device

	Unadjusted			Matched (1:3 Propensity match)		
Variable *n* (%)[a]	**TAVR without CPD (103,935)**	**TAVR with CPD (4380)**	**p value**	**TAVR without CPD (13,140)**	**TAVR with CPD (4380)**	**p value**
In-hospital mortality	1510(1.5)	20(0.5)	<0.01	135(1.0)	20(0.5)	<0.01
Discharge disposition						
Routine	68,755(66.2)	3145(71.8)	<0.01	8710(66.3)	3145(71.8)	<0.01
Short term care hospital	400(0.4)	<11(<0.2)		35(0.3)	<11(<0.3)	
Home health care	20,215(19.4)	770(17.6)		2580(19.6)	770(17.6)	
Complications and resource utilization						
Cardiogenic shock	2050(2.0)	60(1.4)	0.01	170(1.3)	60(1.4)	0.7
Respiratory complications	6525(6.3)	170(3.9)	<0.01	745(5.7)	170(3.9)	<0.01
Acute kidney injury	11,070(10.7)	355(8.1)	<0.01	1190(9.1)	355(8.1)	0.05
Neurological complications	2600(2.5)	75(1.7)	<0.01	340(2.6)	75(1.7)	<0.01
Hemorrhagic stroke	115(0.1)	-	0.03	20(0.2)	-	0.01
Ischemic stroke	2070(2.0)	60(1.4)	<0.01	270(2.1)	60(1.4)	<0.01
Transient ischemic attack	305(0.3)	<11(<0.2)	0.43	40(0.3)	<11(<0.3)	0.41
Vascular complications	4380(4.2)	175(4.0)	0.48	540(4.1)	175(4.0)	0.74
Major bleeding	1070(1.0)	25(0.6)	0.003	95(0.7)	25(0.6)	0.29
Cardiac arrest with CPR	1290(1.2)	20(0.5)	<0.01	125(1.0)	20(0.5)	<0.01
Prolong mechanical vent	965(0.9)	15(0.3)	<0.01	525(4.0)	155(3.5)	0.04
Short term intubation	3905(3.8)	140(3.2)	0.06	525(4.0)	155(3.5)	0.18
Permanent pacemakers	10,405(10.0)	425(9.7)	0.51	1315(10.0)	425(9.7)	0.56
Length of stay, median (IQR), days	2(1–4)	2(1–4)	<0.01	2(1–4)	2(1–4)	<0.01
Cost of hospitalization, median (IQR) $	44,880(35,113–57,230)	44,861(36,953–57,254)	<0.01	44,881(35,113–57,231)	44,861(36,953–57,255)	<0.01

Abbreviations: CPD, cerebral protection device; TAVR; transcatheter aortic valve replacement.

Note: Major bleeding requiring blood transfusion.

[a]<11 numbers not reported per HCUP recommendations.

TABLE 3

Readmission cohort

	Index	Not readmitted	readmitted
2017			
TAVR without CPD	27,463	23,570(85.8)	3893(14.2)
TAVR with CPD	235	195(83.0)	40(17.0)
2018			
TAVR without CPD	29,379	25,232(85.9)	4147(14.1)
TAVR with CPD	1874	1659(88.5)	215(11.5)

Association of CPD with readmissions and 30-days post procedure stroke

	Hazard ratio (HR)	Confidence Interval (CI)	p value
CPD with stroke	0.727	0.554–0.955	0.02
CPD with Readmissions	0.839	0.773–0.911	<0.01

Abbreviations: CI; confidence interval; HR; hazard ratio.