Society for Vascular Surgery Vascular Registry evaluation of stent cell design on carotid artery stenting outcomes

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Objective: **The Society for Vascular Surgery (SVS) Vascular Registry (VR) collects data on outcomes of carotid endarterectomy and carotid artery stenting (CAS). The purpose of this study was to evaluate the impact of open vs closed cell stent design on the in-hospital and 30-day outcome of CAS.**
Methods: **The VR collects provider-reported data on patients using a Web-based database. Data were analyzed both in-hospital and at 30 days postprocedure. The primary outcome is combined death/stroke/myocardial infarction (MI).**
Results: **As of October 14, 2009, there were 4337 CAS with discharge data and 2397 with 30-day data. Open cell stents (OPEN) were used in 3451 patients (79.6%), and closed cell stents (CLOSED) were used in 866 patients (20.4%). Baseline demographics showed no differences in age, gender, race, and ethnicity. However, the OPEN group had more patients with atherosclerosis (74.5% vs 67.4%; $P = .0003$) as the etiology of carotid artery disease. The OPEN group also had a higher prevalence of preprocedural stroke (25.8% vs 21.4%; $P = .0079$), chronic obstructive pulmonary disease (COPD; 21.0% vs 17.6%; $P = .0277$), cardiac arrhythmia (14.7% vs 11.4%; $P = .0108$), valvular heart disease (7.4% vs 3.7%; $P < .0001$), peripheral vascular disease (PVD; 40.0% vs 35.3%; $P = .0109$), and smoking history (59.0% vs 54.1%; $P = .0085$). There are no statistically significant differences in the in-hospital or 30-day outcomes between the OPEN and CLOSED patients. Further subgroup analyses demonstrated symptomatic patients had a higher event rate than the asymptomatic cohort in both the OPEN and CLOSED groups. Among symptomatic patients, the OPEN patients had a lower (0.43% vs 1.41%; $P = .0349$) rate of in-hospital mortality with no difference in stroke or transient ischemic attack (TIA). There were no differences in 30-day event rates. In asymptomatic patients, there were also no statistically significant differences between the OPEN and CLOSED groups. After risk adjustment, there remained no statistically significant differences between groups of the primary endpoint (death/stroke/MI) during in-hospital or 30 days.**
Conclusion: **In-hospital and 30-day outcomes after CAS were not significantly influenced by stent cell design. Symptomatic patients had higher adverse event rates compared to the asymptomatic cohort. As there is no current evidence of differential outcome between the use of open and closed cell stents, physicians should continue to use approved stent platforms based on criteria other than stent cell design. (J Vasc Surg 2011;54:71-9.)**

Stroke is the third leading cause of death and the leading cause of serious long-term disability in the United States.[1,2] While carotid endarterectomy (CEA) has been established as an effective means for treating carotid artery disease, there are conflicting reports on the safety and efficacy of carotid artery stenting (CAS).[3,4] Furthermore, carotid stents of different structural designs are available. "Open cell" and "closed cell" stent designs differ not only in how the stent struts are connected, they also have a range of free cell area between the metal scaffolding (Table I).[5] Using data from a multicenter European CAS registry, Bosiers et al[5] reported on the potential variation in the CAS complication rates according to stent type, free cell area, and cell design. However, a more recent series reported by Schillinger et al[6] could not support the superiority of a specific stent cell design with respect to outcomes. The influence of stent cell design on CAS outcomes thus remains unclear.

The Society for Vascular Surgery (SVS) Vascular Registry (VR) on carotid procedures was developed to collect long-term outcomes on patients treated with CAS and CEA.[7] As the first societal registry to enroll patients with CAS and CEA, the VR is the largest published database of CAS procedures in the United States. The purpose of this article was to utilize the SVS-VR to evaluate stent cell design on CAS outcomes. The in-hospital (procedure and predischarge) and 30-day outcomes of CAS in patients treated with open cell stents (OPEN) and closed cell stents (CLOSED) are described.

METHODS

VR data are reported by providers through Web-based electronic data capture. The measurement schedule in-

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Table I. Types of stents used in patients with carotid artery stenting

Design	*Manufacturer's name*	*Free cell area (mm^2)*
Closed cell	Wallstent (Boston Scientific, Natick, Mass)	1.08 mm^2
	X-act (Abbott Vascular Devices, Redwood City, Calif)	2.74 mm^2
	NexStent (Endotex, Cupertino, Calif)	4.07 mm^2
Open cell	Precise (Cordis, Miami Lakes, Fla)	5.89 mm^2
	Exponent (Medtronic, Santa Rosa, Calif)	6.51 mm^2
	Protégé (eV3, Plymouth, Minn)	10.71 mm^2
	Acculink (Guidant, Santa Clara, Calif)	11.48 mm^2

As reported in Bosiers et al.[5]

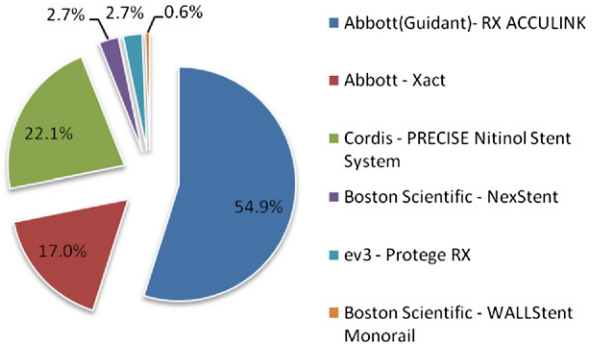

Fig. Distribution of stents used in carotid artery stenting (CAS) patients.

cludes baseline (preoperative) information such as patient demographics, medical history, carotid symptom status, preprocedural diagnostic imaging and laboratory, procedural information, including clinical utility, procedural and predischarge complications; and follow-up information such as postprocedure mortality, stroke, myocardial infarction (MI), and other morbidity. All data entered into the VR are fully compliant with the Health Insurance Portability and Accountability Act regulations and are auditable. All data reports and analyses performed included only deidentified and aggregated data.

New England Research Institutes (NERI, Watertown, Mass) maintains the online database. Funding for the administration and database management of the VR has been provided by the SVS (Chicago, Ill).

Outcomes. The primary outcome measure is a composite of the incidence of death, stroke, and MI. Stroke is defined as any nonconvulsive, focal neurologic deficit of abrupt onset persisting more than 24 hours. The ischemic event must correspond to a vascular territory. An MI is classified as either a Q-wave MI in which one of the following criterion is required: (1) chest pain or other acute symptoms consistent with myocardial ischemia and new pathologic Q waves in two or more contiguous electrocardiogram (ECG) leads; or (2) new pathologic Q waves in two or more contiguous ECG leads and elevation of cardiac enzymes; or non-Q-wave MI, which is defined as CK ratio >2 and CK-MB >1 in the absence of new, pathologic Q waves. In addition, although not considered specific outcomes but of interest, transient ischemic attack (TIA) and amaurosis fugax (or transient monocular blindness [TMB]) are also reported. Analysis of the 30-day outcomes were based on only those patients who had at least a 30-day follow-up visit (≥16 days) or who experienced an endpoint (death, stroke, or MI) within 30 days of treatment.

Procedural success data were also collected. A CAS procedure was deemed successful when all of its components were completed without the need for conversion to CEA, or its abandonment before completion, and <30% residual stenosis achieved postprocedure.

Statistical methods. Tests of statistical significance were conducted with χ^2 or Fisher exact tests for categorical variables and analysis of variance (ANOVA) for continuous variables. Descriptive statistics are listed as mean ± SD for continuous variables and percent (frequency) for categorical variables. Subset analyses were performed using the two-tailed t test for continuous variables and the χ^2 or Fisher exact test, as necessary, for discrete/categorical data. Unadjusted and adjusted odds ratios were used to compare the primary outcomes across treatment groups. Odds ratios were adjusted for any significant baseline factors using logistic regression model. Differences were considered significant if $P < .05$. All statistical analyses were performed by NERI using SAS Statistical Software (Cary, NC).

RESULTS

For the purpose of this report, data collected in the VR from the beginning of electronic data entry on July 11, 2005, to October 14, 2009, were analyzed. There were 4337 patients who had CAS with procedural and discharge data, with 3451 patients (79.6%) in the OPEN group. The distribution of stents used can be found in the Fig. The 30-day cohort contained 2322 patients who had CAS with in-hospital and 30-day outcomes for analyses, of which 1775 patients (76.4%) were in the OPEN group.

Patient characteristics can be found in Table II. While the two groups had similar age, race, and ethnicity, the OPEN group had fewer male patients that almost reached statistical significance (60.4% vs 64.0%; $P = .0534$). The OPEN group had more patients with atherosclerosis (74.5% vs 67.4%; $P = .0003$) as the etiology of carotid artery disease. The OPEN group also had a higher prevalence of stroke (25.8% vs 21.4%; $P < .0079$), chronic obstructive pulmonary disease (COPD; 21.0% vs 17.6%; $P < .0277$), cardiac arrhythmia (14.7% vs 11.4%; $P = .0108$), valvular heart disease (7.4% vs 3.7%; $P < .0001$), peripheral vascular disease (PVD; 40.0% vs 35.3%; $P < .0109$), and smoking history (59.0% vs 54.1%; $P < .0085$). There was no statistically significant difference in symptomatology (47.3% OPEN vs 48.2% CLOSED). The degree of stenosis by contrast angiography was slightly higher and statistically significant in the CLOSED group (86.51% vs 85.75%; $P = .0212$), but the overall amount of patients

Table II. Baseline demographics, disease etiology, medical history, and carotid evaluation of patients with carotid artery stenting by stent design

	OPEN (n = 3451)	*CLOSED (n = 886)*	P *value*
Age (year, range)	71.01 (23-96)	71.25 (37-95)	.5172
Gender (male %)	60.4% (2084/3451)	64.0% (567/886)	.0534
Race (white %)	92.1% (3178/3451)	93.9% (832/886)	.0743
Ethnicity (Hispanic %)	5.1% (175/3451)	3.8% (34/886)	.1352
Carotid disease etiology			
Atherosclerosis	74.5% (2570/3451)	67.4% (597/886)	.0003
Dissection	0.6% (21/3451)	0.2% (2/886)	
Fibromuscular dysplasia	0.2% (6/3451)	0.2% (2/886)	
Radiation	4.0% (139/3451)	4.2% (37/886)	
Trauma	0.1% (3/3451)	0.0% (0/886)	
Restenosis	20.0% (689/3451)	27.3% (242/886)	
Other	0.7% (23/3451)	0.7% (6/886)	
Medical history			
Coronary artery disease	61.1% (2107/3451)	60.3% (534/886)	.6714
Myocardial infarction	21.5% (741/3451)	22.3% (198/886)	.5833
Valvular heart disease	7.4% (256/3451)	3.7% (33/886)	<.0001
Cardiac arrhythmia	14.7% (509/3451)	11.4% (101/886)	.0108
Congestive heart failure	14.6% (504/3451)	12.2% (108/886)	.0661
Hypertension	82.4% (2843/3451)	82.2% (728/886)	.8823
Diabetes	33.9% (1171/3451)	34.8% (308/886)	.6622
Transient ischemic attack	22.6% (780/3451)	22.5% (199/886)	.9641
Stroke	25.8% (890/3451)	21.4% (190/886)	.0079
COPD	21.0% (723/3451)	17.6% (156/886)	.0277
Chronic renal failure	3.7% (128/3451)	3.5% (31/886)	.8413
Amaurosis fugax (TMB)	6.7% (232/3451)	6.8% (60/886)	.9402
Peripheral vascular disease	40.0% (1381/3451)	35.3% (313/886)	.0109
Gastrointestinal ulcer/bleeding	3.9% (135/3451)	2.8% (25/886)	.1344
Current or past smoker	59.0% (2036/3451)	54.1% (479/886)	.0085
Cancer	16.5% (571/3451)	16.9% (150/886)	.8003
Coagulopathy	0.8% (27/3451)	0.7% (6/886)	1.0000
ASA grade			
≤2	89.0% (3071/3451)	89.4% (792/886)	.7631
>2	11.0% (380/3451)	10.6% (94/886)	
NYHA Scale			
≤3	88.6% (3057/3451)	90.5% (802/886)	.1046
>3	11.4% (394/3451)	9.5% (84/886)	
Antiplatelet use	97.0% (3346/3451)	96.7% (857/886)	.7440
Carotid evaluation			
Carotid symptomatology (% symptomatic)	47.3% (1633/3451)	48.2% (427/886)	.6510
Baseline stenosis % (mean, range)	85.75 (0-100)	86.51 (40-100)	.0212
Stenosis >80%	64.3% (2209/3451)	65.5% (574/886)	.5273
Baseline ultrasound >80%	76.2% (2230/3451)	78.8% (617/886)	.1397
Contralateral stenosis >70%	25.9% (752/3451)	26.3% (204/886)	.8178
Use of embolic protection	97.1% (3350/3451)	98.5% (873/886)	.0133
Number of stents			
1	93.6% (3231/3451)	94.5% (837/886)	.3766
2	5.9% (204/3451)	4.9% (43/886)	
3	0.4% (14/3451)	0.7% (6/886)	
4	0.1% (2/3451)	0.0% (0/886)	

ASA, American Society of Anesthesiology; *CLOSED,* closed cell stent; *COPD,* chronic obstructive pulmonary disease; *NYHA,* New York Heart Association; *OPEN,* open cell stent; *TMB,* transient monocular blindness.
P values for age and baseline stenosis percentage were found using *t* test. *P* value for etiology was found using χ^2 test. all other *P* values were found using Fisher exact tests.

with stenosis >80% or contralateral stenosis >70% were similar between the two groups. While the OPEN group was associated with a lower use of embolic protection (97.1% vs 98.5%; $P = .0133$), the number of stents used per patient was similar.

In-hospital outcomes. There were no statistically significant differences between the in-hospital adverse event rates for the OPEN and CLOSED groups (Table III). However, in general, the OPEN group had lower event rates, such as stroke (1.85% vs 2.14%) and the primary outcome of combined death/stroke/MI (2.46% vs 3.16%). After adjusting for significant baseline factors such as etiology (atherosclerosis), valvular heart disease, cardiac arrhythmia, stroke, COPD, PVD, smoking status, percent baseline stenosis, and use of embolic protection (Table IV), the OPEN group had a statistically significant lower rate of

Table III. In-hospital outcomes in OPEN versus CLOSED patients

In-hospital outcomes	*OPEN (n = 3451) n (%)*	*CLOSED (n = 886) n (%)*	P *value*
Death, stroke, or MI	85 (2.46)	28 (3.16)	.2386
Death, stroke, or TIA	111 (3.22)	38 (4.29)	.1213
Mortality	18 (0.52)	8 (0.90)	.2192
Stroke	64 (1.85)	19 (2.14)	.5825
MI	15 (0.43)	5 (0.56)	.5816
TIA	36 (1.04)	14 (1.58)	.2146
TMB	7 (0.20)	3 (0.34)	.4366

CLOSED, Closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *TIA,* transient ischemic attack; *TMB,* transient monocular blindness. *P* values were based on Fisher exact test. Outcomes are defined as any event intraoperatively or predischarge. Rates are per patient.

combined death/stroke/TIA (odds ratio [OR], 0.674; 95% confidence interval [CI], 0.460-0.987; $P = .0427$). However, there remained no statistically significant differences in the rates of death, stroke, MI, or combined primary endpoint.

In comparing symptomatology (Table V), there was a statistically significant difference with an increase in the incidence of stroke for symptomatic patients in both groups. In the OPEN group, symptomatic patients had a higher incidence of stroke (2.51% vs 1.27%; $P < .0077$) and combined death/stroke/MI (3.18% vs 1.82%; $P = .0111$). In the CLOSED cohort, symptomatic patients also had a higher incidence of stroke (3.51% vs 0.87%; $P = .0091$), as well as combined death/stroke/MI (5.15% vs 1.31%; $P = .0016$) and combined death/stroke/TIA rates (6.09% vs 2.61%; $P = .0124$). When comparing symptomatic patients by stent design (Table VI), the OPEN patients had a statistically significant lower incidence of mortality (0.43% vs 1.41%; $P = .0349$), but the difference in stroke rate was not statistically significant (2.51% vs 3.51%), nor was the difference in combined death/stroke/MI rate (3.18% vs 5.15%; $P = .0577$). In asymptomatic patients (Table VI), there were no statistically significant differences for the in-hospital outcomes between the OPEN and CLOSED groups.

Thirty-day outcomes. Similar to the in-hospital outcomes, there were no statistically significant differences between the 30-day adverse event rates for the OPEN and CLOSE groups (Table VII). However, in contrast to the in-hospital findings, there is a reversal with a higher incidence of stroke in the OPEN group (2.54% vs 1.65%). The primary outcome of combined death/stroke/MI was 4.11% in the OPEN group and 3.66% in the CLOSED group. After adjusting for baseline risk factors (Table VIII), there were no statistically significant differences in the event rates between the two groups.

When comparing symptomatology (Table IX) in the OPEN group, there was a statistically significant difference with an increase in the incidence of stroke (3.64% vs 1.63%; $P = .0093$) and TIA (2.39% vs 0.92%; $P = .0200$) for symptomatic patients compared with asymptomatic patients. This led to higher rates of combined death/stroke/MI (5.28% vs 3.17%; $P = .0302$) and combined death/stroke/TIA (6.91% vs 3.78%; $P = .0035$). There were no statistically significant differences in outcomes between symptomatic and asymptomatic cohorts for the CLOSED group. When comparing symptomatic patients by stent design (Table X), there were no statistically significant differences in outcomes. However, it is important to point out that in the OPEN group, there was a higher incidence of stroke (3.64% vs 1.89%) and combined death/stroke/MI (5.28% vs 4.53%) compared with the CLOSED group. In asymptomatic patients (Table X), there were also no statistically significant differences between the OPEN and CLOSED groups. The primary endpoint of combined death/stroke/MI was 3.17% for OPEN patients and 2.84% for CLOSED patients.

Secondary outcomes. Secondary outcomes are shown in Table XI. The OPEN group had 100% technical success, while the CLOSED group had two technical failures (99.8% success; $P = .0417$). Patients in the OPEN group were more likely to have developed intraprocedural spasm requiring treatment (2.1% vs 0.3%; $P = .0001$) and hypotension requiring treatment (6.9% vs 3.7%; $P = .0003$).

DISCUSSION

Since its introduction in the 1990s, CAS offers an alternative to CEA in the treatment of carotid artery stenosis. Despite large randomized controlled trials, the safety and efficacy of CAS compared to CEA remain uncertain.[3,4] Several patient-specific factors have been shown to be associated with poor CAS outcomes. These include advanced patient age, extensive calcification of the aortic arch, and presence of an internal carotid artery thrombus. To further confound the results of CAS, this procedure can be performed with a number of stents with different structural designs. As different stent designs can exhibit variable mechanical properties, this may lead to differential results after CAS.[8] The "ideal" stent should demonstrate high flexibility in order to navigate through difficult access anatomy and accommodate tortuous target vessels. The benefits of improved deliverability and conformability must be balanced with a high resistance to particle penetration with adequate carotid plaque coverage to prevent embolization of debris. Depending on the design, stents can be divided into those with an open cell or closed cell configuration. Closed cell stents are characterized by smaller free cell areas between struts, thus leaving smaller gaps uncovered. However, they are less flexible than open cell stents. While it has been estimated that all types of stents will achieve similar outcomes in approximately 75% of all CAS procedures, the remaining quarter requires careful preoperative screening.[9]

There are conflicting reports in the current literature regarding the influence of stent cell design on CAS outcomes. In a nonrandomized study by Bosiers et al,[9] 3179 patients treated with CAS in four centers with high-volume experience were included.[5] The results showed that patients who underwent CAS with a closed cell stent experi-

Table IV. Risk-adjusted odds ratios for in-hospital outcomes

	Unadjusted OPEN (vs CLOSED)			*Adjusted OPEN (vs CLOSED)*		
In-hospital outcomes	*OR*	*95% CI*	P *value*	*OR*	*95% CI*	P *value*
Death	0.575	0.249-1.328	.1952	0.515	0.218-1.213	.1287
Stroke	0.862	0.514-1.447	.5745	0.781	0.462-1.320	.3562
MI	0.769	0.279-2.121	.6120	0.738	0.265-2.061	.5624
TIA	0.657	0.353-1.223	.1848	0.621	0.331-1.167	.1390
TMB	0.598	0.154-2.318	.4572	0.493	0.123-1.984	.3196
Death/stroke/MI	0.774	0.501-1.194	.2460	0.710	0.457-1.102	.1264
Death/stroke/TIA	0.741	0.509-1.080	.1188	0.674	0.460-0.987	.0427

CI, Confidence interval; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *OR,* odds ratio; *TIA,* transient ischemic attack; *TMB,* transient monocular blindness.
Adjusted ORs calculated after adjusting for etiology (atherosclerosis), valvular heart disease, cardiac arrhythmia, stroke, COPD, peripheral vascular disease, smoking status, baseline stenosis, and use of embolic protection. *P* values were found using χ^2.

Table V. In-hospital outcomes for cell design by symptomatology

	OPEN			*CLOSED*		
In-hospital outcomes	*SYMPT (n = 1633) n (%)*	*ASYMP (n = 1818) n (%)*	P *value*	*SYMPT (n = 427) n (%)*	*ASYMP (n = 459) n (%)*	P *value*
Death, stroke, or MI	52 (3.18)	33 (1.82)	.0111	22 (5.15)	6 (1.31)	.0016
Death, stroke, or TIA	63 (3.86)	48 (2.64)	.0529	26 (6.09)	12 (2.61)	.0124
Mortality	7 (0.43)	11 (0.61)	.6373	6 (1.41)	2 (0.44)	.1641
Stroke	41 (2.51)	23 (1.27)	.0077	15 (3.51)	4 (0.87)	.0091
MI	7 (0.43)	8 (0.44)	1.0000	4 (0.94)	1 (0.22)	.2020
TIA	18 (1.10)	18 (0.99)	.8671	8 (1.87)	6 (1.31)	.5943

ASYMP, Asymptomatic; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *SYMPT,* symptomatic; *TIA,* transient ischemic attack.
P values were based on Fisher exact test. Outcomes are defined as occurring intraoperatively or predischarge. Rates are per patient.

Table VI. In-hospital outcomes for symptomatic and asymptomatic patients by stent cell design

	SYMP			*ASYMP*		
In-hospital outcomes	*OPEN (n = 1633) n (%)*	*CLOSED (n = 427) n (%)*	P *value*	*OPEN (n = 1818) n (%)*	*CLOSED (n = 459) n (%)*	P *value*
Death, stroke, or MI	52 (3.18)	22 (5.15)	.0577	33 (1.82)	6 (1.31)	.5497
Death, stroke, or TIA	63 (3.86)	26 (6.09)	.0600	48 (2.64)	12 (2.61)	1.0000
Mortality	7 (0.43)	6 (1.41)	.0349	11 (0.61)	2 (0.44)	1.0000
Stroke	41 (2.51)	15 (3.51)	.2456	23 (1.27)	4 (0.87)	.6324
MI	7 (0.43)	4 (0.94)	.2542	8 (0.44)	1 (0.22)	.6968
TIA	18 (1.10)	8 (1.87)	.2221	18 (0.99)	6 (1.31)	.6074

ASYMP, Asymptomatic; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *SYMPT,* symptomatic; *TIA,* transient ischemic attack.
P values were based on Fisher exact test. Outcomes are defined as occurring intraoperatively or predischarge. Rates are per patient.

enced a lower (3.4% vs 1.3%; $P < .02$) rate of postprocedural events (TIA/stroke/death). This finding was even more pronounced in symptomatic patients, with a clear reduction (6.3% vs 1.3%; $P < .0001$) for the closed cell group. In the asymptomatic population, free cell area did not influence event rates. In another study by Schillinger et al,[6] 1684 patients from 10 European centers were evaluated. The combined TIA/stroke/death rate within 30 days were 6.1% for the closed cell group compared to 4.1% for the open cell group ($P = .077$). Furthermore, multivariate analyses also did not support the superiority of a specific carotid stent cell design with respect to neurologic complications, stroke, and mortality risk. Subsequent studies with smaller patient samples have continued to show conflicting results.[10,11] The influence of stent cell design on CAS outcomes thus remains unclear.

Using data from the SVS-VR, outcomes on 4377 patients who underwent CAS were evaluated. In this registry, patients treated with open cell stents had a higher incidence of atherosclerosis as the etiology of carotid artery stenosis.

Table VII. Thirty-day outcomes in OPEN versus CLOSED patients

Thirty-day outcomes	*OPEN (n = 1775) n (%)*	*CLOSED (n = 547) n (%)*	P *value*
Death, stroke, or MI	73 (4.11)	20 (3.66)	.7091
Death, stroke, or TIA	92 (5.18)	27 (4.94)	.9118
Mortality	25 (1.41)	10 (1.83)	.5463
Stroke	45 (2.54)	9 (1.65)	.2592
MI	13 (0.73)	4 (0.73)	1.0000
TIA	28 (1.58)	10 (1.83)	.7004
TMB	4 (0.23)	3 (0.55)	.3661

CLOSED, Closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *TIA,* transient ischemic attack; *TMB,* transient monocular blindness. *P* values were based on Fisher exact test. Outcomes were defined as occurring intraoperatively, predischarge, or between discharge and 30 days. Rates are per patient.

The OPEN group had a statistically significant higher prevalence of several major medical comorbidities. Despite this, there were no statistically significant differences in rates of death/stroke/MI either in-hospital or 30 days after discharge between the OPEN and CLOSED groups. When comparing symptomatology, it was not surprising to find that symptomatic patients had a higher stroke rate in-hospital for both the OPEN and CLOSED patients. The higher in-hospital stroke rate for symptomatic patients in this registry had been demonstrated in a prior report.[7] At 30 days, this trend continued for the OPEN group but symptomatology had no effect on outcomes in CLOSED patients. With symptomatic patients, there was a statistically significant lower rate of in-hospital mortality (0.43% vs 1.41%; $P = .0349$; Table VI) for the OPEN group. However, there were no differences in the rates of stroke, MI, or TIA. The lower incidence of combined death/stroke/MI (3.18% vs 5.15%; $P = .0577$) for the OPEN group also had approached, but did not reach, statistical significance. In contrast to the in-hospital findings, the OPEN group had a higher (5.28% vs 4.53%; $P = .75$) rate of combined death/stroke/MI at 30 days. There were no other differences noted in the symptomatic subgroup. Similar to the published literature, stent cell design had no influence on CAS outcomes in the asymptomatic population. Overall, the in-hospital and 30-day outcomes after CAS were not significantly influenced by stent cell design in this study.

Several nonpatient-related factors have been shown to play a role in the outcome of CAS. There is a significant procedure-related learning curve and numerous studies have demonstrated the importance of operator experience in the clinical success of CAS.[12-14] Analyses of complications of CAS have highlighted the significant contribution of embolization originating from sources proximal to the treated lesion.[14-16] As neurologic events can occur in the contralateral hemisphere as well as before crossing the internal carotid lesion, manipulation with wires, catheters, and sheaths in a tortuous or diseased aortic arch or common carotid arteries can contribute to the complications seen with CAS. To reduce the embolic load associated with femoral access, some investigators have proposed the performance of CAS through a cervical access. While there lacks high-quality randomized data, reports of transcervical CAS, either through a percutaneous or surgical approach, have suggested improved outcomes compared to the traditional transfemoral approach.[17-20] While there are nonpatient-related factors that contribute a significant role in the outcome of CAS, stent cell design had no statistically significant effect in this study and has not been consistently demonstrated to play a role based on available literature.

Several distinguishing features of this study merit emphasis. Compared to previous reports, this study includes the largest patient sample and represents the most contemporary experience, with data collection beginning in 2005. Furthermore, the SVS-VR is available to all clinical facilities and providers in the United States wishing to participate. As such, while the registry suffers from self-reporting bias, it includes a broader collection of institutions and physicians, thus possibly presenting data that coincides with results found in the "real world." With respect to patient characteristics, the proportion (47.5%) of symptomatic patients in this study is comparable to those in the previous studies. A significant difference with this study population is that the vast majority of patients (80%) had placement of open cell stents. In contrast, only 30% of the Bosiers et al[5] series and 49% of the Schillinger et al[6] series were treated with open cell stents. Any potential effect of this discrepancy with the previous studies is unknown.

Some limitations of this study should be discussed. While this is the largest patient sample to evaluate the influence of stent cell design on CAS outcomes, there remains the possibility of a type II error. As there are excellent results with both open and closed cell stents, the current number of patients may not have enough power to detect a clinical difference between the two groups. With this in mind, the current study suggests that the influence of stent design is so minimal that no statistically significant differences in clinical outcomes are detectable.

While the results of this study contrast those findings by Bosier et al,[5] a possible explanation of this may be our inability to differentiate the timing of neurologic complications. Verzini et al[14] have demonstrated that there are differential stroke risks associated with temporal phases of the CAS procedure. In trying to explain neurologic events that occur in the early and late postinterventional phases (ie, after recovery of the embolic protection device), they hypothesized that this is when the selection of stent material and design may play a more prominent role than the "learning-curve effect" or patient anatomy. Within the design of the SVS-VR, there is no differentiation of the timing of the neurologic events and as such, further analyzes are not possible to differentiate "procedural" and "postprocedural" events. While the differences remained statistically not significant, it is interesting to point out that the CLOSED group had a higher in-hospital event rate but a lower rate of 30-day outcomes compared to the OPEN

Table VIII. Risk-adjusted odds ratios for 30-day outcomes

	Unadjusted OPEN (vs CLOSED)			*Adjusted OPEN (vs CLOSED)*		
Thirty-day outcomes	*OR*	*95% CI*	P *value*	*OR*	*95% CI*	P *value*
Death	0.755	0.372-1.532	.4361	0.677	0.328-1.395	.2902
Stroke	1.108	0.677-1.815	.6825	1.000	0.607-1.649	.9994
MI	1.239	0.463-3.316	.6697	1.194	0.442-3.221	.7264
TIA	0.947	0.524-1.709	.8556	0.893	0.492-1.624	.7118
TMB	0.492	0.160-1.511	.2155	0.425	0.135-1.339	.1438
Death/stroke/MI	1.032	0.691-1.541	.8772	0.943	0.628-1.416	.7778
Death/stroke/TIA	0.982	0.690-1.397	.9202	0.892	0.623-1.276	.5305

CI, Confidence interval; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *OR,* odds ratio; *TIA,* transient ischemic attack; *TMB,* transient monocular blindness.
Adjusted ORs calculated after adjusting for etiology (atherosclerosis), valvular heart disease, cardiac arrhythmia, stroke, COPD, peripheral vascular disease, smoking status, baseline stenosis, and use of embolic protection. *P* values were found using χ^2.

Table IX. Thirty-day outcomes for cell design by symptomatology

	OPEN			*CLOSED*		
Thirty-day outcomes	*SYMPT (n = 796) n (%)*	*ASYMP (n = 979) n (%)*	P *value*	*SYMPT (n = 265) n (%)*	*ASYMP (n = 282) n (%)*	P *value*
Death, stroke, or MI	42 (5.28)	31 (3.17)	.0302	12 (4.53)	8 (2.84)	.3639
Death, stroke, or TIA	55 (6.91)	37 (3.78)	.0035	15 (5.66)	12 (4.26)	.5545
Mortality	10 (1.26)	15 (1.53)	.6890	6 (2.26)	4 (1.42)	.5343
Stroke	29 (3.64)	16 (1.63)	.0093	5 (1.89)	4 (1.42)	.7453
MI	6 (0.75)	7 (0.72)	1.0000	3 (1.13)	1 (0.35)	.3587
TIA	19 (2.39)	9 (0.92)	.0200	6 (2.26)	4 (1.42)	.5343

ASYMP, Asymptomatic; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *SYMPT,* symptomatic; *TIA,* transient ischemic attack.
P values were based on Fisher exact test. Outcomes are defined as occurring intraoperatively, predischarge, or between discharge and 30 days. Rates are per patient.

Table X. Thirty-day outcomes for symptomatic and asymptomatic patients by stent cell design

	SYMP			*ASYMP*		
Thirty-day outcomes	*OPEN (n = 796) n (%)*	*CLOSED (n = 265) n (%)*	P *value*	*OPEN (n = 979) n (%)*	*CLOSED (n = 282) n (%)*	P *value*
Death, stroke, or MI	42 (5.28%)	12 (4.53%)	.7475	31 (3.17%)	8 (2.84%)	1.0000
Death, stroke, or TIA	55 (6.91%)	15 (5.66%)	.5682	37 (3.78%)	12 (4.26%)	.7270
Mortality	10 (1.26%)	6 (2.26%)	.2498	15 (1.53%)	4 (1.42%)	1.0000
Stroke	29 (3.64%)	5 (1.89%)	.2255	16 (1.63%)	4 (1.42%)	1.0000
MI	6 (0.75%)	3 (1.13%)	.6984	7 (0.72%)	1 (0.35%)	.6923
TIA	19 (2.39%)	6 (2.26%)	1.0000	9 (0.92%)	4 (1.42%)	.5027

ASYMP, Asymptomatic; *CLOSED,* closed cell stent; *MI,* myocardial infarction; *OPEN,* open cell stent; *SYMPT,* symptomatic; *TIA,* transient ischemic attack.
P values were based on Fisher exact test. Outcomes are defined as occurring intraoperatively, predischarge, or between discharge and 30 days. Rates are per patient.

group. This may suggest a benefit of the closed cell stents in later follow-up and that inclusion of "procedural" events may have diluted out any potential differences between the two groups.

There are also limitations specific to secondary data analyses of databases such as the SVS-VR. It must be again noted that data are self-reported by treating physicians/institutions. The potential impact of reporting bias within the registry has previously been investigated and discussed.[7] Furthermore, the SVS-VR was not designed to mimic clinical trials involving CAS. As such, information regarding additional clinical variables (such as target vessel diameter, degree of tortuosity, type of embolic protection, plaque characteristics) simply was not available, and any confounding effects these factors may have had on the study outcomes cannot be adequately analyzed. Furthermore, as the Center for Medicare and Medicaid Services only require in-hospital data for CAS certification, some

Table XI. Secondary outcomes for CAS patients by stent design

Clinical utility and secondary outcomes	*Open (n = 3451) n (%)*	*Closed (n = 886) n (%)*	P *value*
Hospital length of stay, days (range)	2.66 (0-134)	2.44 (0-42)	.1854
Procedural technical success	100.0% (3451/3451)	99.8% (884/886)	.0417
Intraprocedural events			
Abrupt closure	0.1% (4/3451)	0.1% (1/886)	1.0000
Spasm requiring treatment	2.1% (71/3451)	0.3% (3/886)	.0001
Loss of external carotid artery	0.1% (3/3451)	0.0% (0/886)	1.0000
Embolization (systemic)	0.0% (1/3451)	0.1% (1/886)	.3669
Embolization (carotid)	0.1% (5/3451)	0.1% (1/886)	1.0000
Thrombosis	0.3% (9/3451)	0.1% (1/886)	.6978
Occlusive untreated dissection	0.0% (1/3451)	0.0% (0/886)	1.0000
Arrhythmia (treated)	1.6% (54/3451)	1.4% (12/886)	.7590
Hypotension (treated)	6.9% (238/3451)	3.7% (33/886)	.0003
Seizure	0.1% (3/3451)	0.0% (0/886)	1.0000
Puncture site complication	0.4% (13/3451)	0.1% (1/886)	.3258

P value for hospital length of stay was based on *t* test; all other *P* values are based on Fisher exact test. Rates are reported per patient.

providers have chosen to not submit follow-up data. As a result, a significant portion of the registry does not have data available for 30-day analysis. Finally, as with all studies using registry data, all collected information is retrospective in nature. However, in the absence of randomized evidence, data from independent and verifiable registries still can provide valuable information about clinical outcomes.

CONCLUSION

Although the OPEN group had a statistically significant higher prevalence of medical comorbidities, there were no statistically significant differences in the in-hospital or 30-day rate of death/stroke/MI. Symptomatic patients had higher adverse event rates compared to the asymptomatic cohort. At this time, there is no evidence of differential outcome between the use of open and closed cell stents. However, given the low event rates, larger population studies may be required to detect small differences in CAS outcomes based on stent cell design. Further randomized studies may also provide additional insight. Until then, physicians should continue to use approved stent platforms based on criteria other than stent cell design.

AUTHOR CONTRIBUTIONS

Conception and design: JJ, GS
Analysis and interpretation: JJ, CK, FS
Data collection: CK, FS
Writing the article: JJ, BR, GL, FS, GS
Critical revision of the article: JJ, BR, GL, CK, FS, GS
Final approval of the article: JJ, BR, GL, FS, GS
Statistical analysis: CK, FS
Obtained funding: GS
Overall responsibility: JJ, GS

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