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Predictors of prolonged length of stay after elective carotid revascularization

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ABSTRACT

Objective: Postoperative day-one discharge is used as a quality-of-care indicator after carotid revascularization. This study identifies predictors of prolonged length of stay (pLOS), defined as a postprocedural LOS of >1 day, after elective carotid revascularization.

Methods: Patients undergoing carotid endarterectomy (CEA), transcarotid artery revascularization (TCAR), and transfemoral carotid artery stenting (TFCAS) in the Vascular Quality Initiative between 2016 and 2022 were included in this analysis. Multivariable logistic regression analysis was used to identify predictors of pLOS, defined as a postprocedural LOS of >1 day, after each procedure.

Results: A total of 118,625 elective cases were included. pLOS was observed in nearly 23.2% of patients undergoing carotid revascularization. Major adverse events, including neurological, cardiac, infectious, and bleeding complications, occurred in 5.2% of patients and were the most significant contributor to pLOS after the three procedures. Age, female sex, non-White race, insurance status, high comorbidity index, prior ipsilateral CEA, non-ambulatory status, symptomatic presentation, surgeries occurring on Friday, and postoperative hypo- or hypertension were significantly associated with pLOS across all three procedures. For CEA, additional predictors included contralateral carotid artery occlusion, preoperative use of dual antiplatelets and anticoagulation, low physician volume (<11 cases/year), and drain use. For TCAR, preoperative anticoagulation use, low physician case volume (<6 cases/year), no protamine use, and post-stent dilatation intraoperatively were associated with pLOS. One-year analysis showed a significant association between pLOS and increased mortality for all three procedures; CEA (hazard ratio [HR],1.64; 95% confidence interval [CI], 1.49-1.82), TCAR (HR,1.56; 95% CI, 1.35-1.80), and TFCAS (HR, 1.33; 95%CI, 1.08-1.64) (all $P < .05$).

Conclusions: A postoperative LOS of more than 1 day is not uncommon after carotid revascularization. Procedure-related complications are the most common drivers of pLOS. Identifying patients who are risk for pLOS highlights quality improvement strategies that can optimize short and 1-year outcomes of patients undergoing carotid revascularization. (J Vasc Surg 2024;■:1-11.)

Keywords: Carotid endarterectomy; Carotid revascularization; Length of stay; Quality improvement; Risk factors; Transcarotid artery revascularization; Transfemoral carotid artery stenting

As health care costs continue to grow in the United States, there has been a focus on providing high-quality health care in the most cost-effective way. Prolonged hospital length of stay (pLOS) after routine procedures has been cited as a quality metric to reduce cost and hospital-acquired morbidity.[1] Patient factors, outcomes, and institutional-related issues are usually implicated as driving factors behind pLOS. For carotid endarterectomy (CEA), a hospital LOS >1 day has been defined by the Society for Vascular Surgery Vascular Quality Initiative (VQI) as a pLOS. The VQI sends reports to hospitals regarding center profile and opportunities for improvement,

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including percentage of patients staying longer than 1 postoperative day after carotid procedures, which serves as a quality indication.[2] With the evolution of minimally invasive carotid revascularization, such as transfemoral carotid artery stenting (TfCAS) and transcarotid revascularization (TCAR), metrics such as LOS are becoming increasingly important.

Increased LOS after CEA has been shown to be associated with increased hospital charges and costs, as well as significant morbidity and mortality.[1] Multiple studies have investigated various risk factors driving this increase to guide quality improvement efforts designed to reduce LOS after CEA.[1-8] In addition to patient characteristics (congestive heart failure, female sex, and chronic obstructive pulmonary disease), pLOS has been shown to be associated with medication noncompliance and operative factors such as electroencephalography change, operating room start time after noon, the need for postoperative blood pressure control, intensive care unit admission, Foley catheter or drain placement, and completion imaging, as well as in-hospital complications..[2,3,7] After identifying significant regional variation in LOS after CEA, Ross et al suggested that differences in patient mix or region- or center-specific factors, such as case volume, complication rates, or surgeon care preference could be unmeasured causes of longer LOS in some regions.[8]

Despite multiple studies on LOS after CEA, few have investigated the contributions of aggregates of preoperative, operative, and postoperative variables as well as patient- and hospital-level factors on pLOS. Moreover, studies on the predictors of pLOS after TfCAS and TCAR are scarce. Limiting postoperative LOS after CEA, TfCAS, and TCAR is important from the perspectives of quality, patient experience, efficiency, and reimbursement.[7] This study aims to identify factors associated with increased LOS after elective carotid revascularization procedures. Identifying modifiable preoperative, intraoperative, and postoperative factors can guide future quality improvement strategies that aim at reducing the incidence of pLOS and improving the care of the high-risk vascular surgery population.

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective review of prospectively collected Vascular Quality Initiative data
- **Key Findings:** A postoperative length of stay (LOS) of greater than 1 day occurred in nearly 23% of patients undergoing elective carotid revascularization. Increased LOS was associated with higher 1-year mortality rates. Predictors of LOS included age, female sex, non-White race, insurance status, high comorbidity index, prior ipsilateral carotid endarterectomy, nonambulatory and symptomatic status, surgeries occurring on Friday, postoperative complications, and hemodynamic instability. Furthermore, contralateral carotid artery occlusion, preoperative use of dual antiplatelets and anticoagulation, low physician volume, and drain use contributed to increased LOS after carotid endarterectomy, whereas preoperative anticoagulation use, low physician case volume, no protamine use, and post-stent dilatation were associated with increased LOS after transcarotid artery revascularization.
- **Take Home Message:** Although many factors contributing to prolonged LOS after elective carotid revascularization may be non-modifiable, this study identifies several factors that serve as targets for quality improvement initiatives aimed at enhancing care and reducing LOS.

METHODS

Data source and patient population. The CEA and carotid artery stenting (CAS) modules of the VQI database were queried from 2016 to 2022.VQI is a national clinical registry containing clinical, procedural, and outcomes data from over a million vascular procedures across North America and Canada. More information about the VQI can be found at www.vascularqualityinitiative.org. All patients who underwent elective CEA, TfCAS, and TCAR for atherosclerotic carotid artery stenosis (excluding intracranial procedures) from September 2016 to May 2022 were included. Patients undergoing urgent/emergent procedures, patients with preoperative Rankin score of more than or equal to 3, corresponding to moderate-severe disability, those transferred in from another hospital or from a rehabilitation unit or dying during the index hospitalization, and procedures performed on Saturday or Sunday were excluded. We also excluded patients undergoing CEA with concomitant procedures, and those undergoing TfCAS or TCAR for more than one stenotic lesion, or without a distal embolic protection device or flow reversal, respectively. The study was approved by the Society for Vascular Surgery Patient Safety Organization Research Advisory Subcommittee (ID: 4703). Institutional review board approval and the need for informed consent were waived secondary to the retrospective nature of the study and the use of nonidentifiable data.

Variables. Postoperative LOS was calculated as the length of stay in days between surgery and discharge dates A pLOS for carotid interventions was defined as more than 1 day. Variables analyzed included patients' demographics (age, sex, race), insurance status, symptomatic presentation within 180 days of the procedure, smoking history, and ambulatory statuses (independent, with assistance/wheelchair, bedridden). Medical comorbidities (hypertension, diabetes, coronary artery disease, prior coronary artery bypass grafting or percutaneous interventions, congestive heart failure, chronic obstructive pulmonary disease, chronic kidney disease), history of ipsilateral or contralateral carotid interventions, presence of anatomic high-risk criteria as defined by the Center for Medicare and Medicaid Services (contralateral carotid artery occlusion, prior ipsilateral CEA, radical neck surgery or neck radiation, laryngeal nerve palsy, neck stoma, lesion above C2 or below clavicle, cervical immobility, and severe tandem lesions),[9] preoperative dual antiplatelets, and anticoagulation were analyzed. A combined comorbidity index score was calculated for each patient as the sum of the following scores: 1 point each for history of myocardial infarction (MI), congestive heart failure, peripheral vascular disease, cerebrovascular disease, pulmonary disease, or diabetes, and 2 points for chronic kidney disease.[10] Operative variables included operative time, day of the week of surgery, and CEA technique (conventional or eversion), as well as the use of intraoperative shunting, patch angioplasty, or drain placement during CEA, completion imaging, protamine use, pre-or post-stent balloon angioplasty, and anesthesia technique.

Physicians' case volumes were calculated as the average annual number of each type of carotid intervention. Thus, for each physician participating in VQI, the average number of TCARs, CEAs, and TfCASs per year were calculated. Procedural case volumes were then divided into three groups/tertiles using the *Xtile* function in Stata Physicians with low case volumes were defined as performing less than 11 cases/year for CEA, less than six for TCAR or less than 4.25 for TfCAS. Physicians with high-case volumes included those performing an average of more than 20 CEA procedures, more than 13.8 TCARs, or more than 10.4 TfCAS per year, respectively. Center case volumes were calculated in a similar fashion, with low-volume center defined as having <46.6 cases/year for CEA, <15.5 cases/year for TCAR, and <12.3 cases/year for TfCAS.

Outcomes of carotid revascularization. In-hospital major adverse events (MAEs) included the occurrence of at least one of the following complications: transient ischemic attack (TIA) or stroke, defined as postoperative ipsilateral or contralateral neurologic symptoms lasting < or >24 hours, respectively; cardiac complications (MI, congestive heart failure, dysrhythmia); reperfusion syndrome; cranial nerve injury; bleeding requiring intervention; return to the operating room; surgical site infection; restenosis/occlusion; or pseudoaneurysm formation. Other outcomes reported included post-procedural hypo or hypertension requiring the need for intravenous medication. One-year outcomes included stroke or death.

Statistical analysis. For each carotid revascularization technique, patients' demographics, baseline characteristics, operative variables, and in-hospital outcomes were compared between those with a standard LOS of less than or equal to 1 day (sLOS) and those with pLOS. Continuous variables were presented as mean ± standard deviation or median (interquartile range) and compared using the Student *t*-test or Mann-Whitney *U* test, as appropriate. Categorical variables were described as count (percentage) and compared using χ^2 tests. To identify the predictors of pLOS for each carotid revascularization technique, we added variables that were significantly different on univariable analysis and clinically relevant variables to a logistic regression model clustered by center identifier. Stepwise backward elimination with a prespecified α level of 0.20 was performed. We also used Akaike information criterion to select the most parsimonious model. Each model was tested for goodness of fit using the Hosmer-Lemeshow test and for discriminative ability using the area under the curve statistics. Models were internally validated by bootstrapping with 1000 repetitions. We also studied the association between pLOS and 1-year outcomes using Kaplan-Meier survival analysis and Cox proportional hazards models that considered significant and clinically relevant baseline variables. A $P < .05$ denoted statistical significance. Analysis was performed using STATA/SE 16.1 statistical software (StataCorp).

RESULTS

A total of 118,625 elective cases met criteria for analysis and were included in the study. Of the three procedures, CEA (n = 80,566) was the most common, followed by TCAR (n = 25,087) and TfCAS (n = 12,972). LOS was not normally distributed and had a median of 1 day (range, 0-1097 days). pLOS was observed in 23.6%, 23.6%, and 20.3% of CEA, TCAR, and TfCAS patients, respectively ($P < .01$).

Comparison of baseline characteristics between patients with sLOS and pLOS is shown in Table I. Notably, for all three procedures (CEA, TCAR, and TfCAS), patients with pLOS were older, more likely to be females, non-White, and symptomatic. They also had more comorbidities, non-ambulatory status, and were more likely to be performed by physicians with low-case volumes (CEA and TCAR only) and on a Friday. Operative variables are shown in Table II.

In-hospital complications and MAEs were recorded and were significantly higher in patients with pLOS (Table III). For CEA, the most common complications were return to the operating room, cranial nerve injury, stroke, and bleeding requiring intervention. For TCAR and TfCAS, stroke and dysrhythmia were frequent complications associated with pLOS. Bleeding and return to the operating room were also associated with pLOS after TCAR. Postprocedural hypo and hypertension were significantly associated with pLOS in all three procedures. Patients with pLOS had higher rates of 1-year

Table I. Baseline characteristics

	CEA (n = 80,566)			TCAR (n = 25,087)			TFCAS (n = 12,972)		
	sLoS (76.4%)	pLoS (23.6%)	*P* value	sLoS (76.4%)	pLoS (23.6%)	*P* value	sLoS (79.7%)	pLoS (20.3%)	*P* value
Age, years	71 (65-77)	72 (66-78)	<.001	74 (67-79)	75 (69-81)	<.001	71 (64-77)	73 (66-79)	<.001
Categorical variables									
Female sex	23,328 (37.9)	8383 (44.1)	<.001	6759 (35.3)	2503 (42.4)	<.001	3577 (34.6)	1109 (42.1)	<.001
Non-White race	5118 (8.3)	2504 (13.2)	<.001	1614 (8.4)	652 (11.0)	<.001	895 (8.7)	316 (12.0)	<.001
Symptomatic status	11,760 (19.1)	4837 (25.5)	<.001	3352 (17.5)	1327 (22.5)	<.001	2235 (21.6)	723 (27.5)	<.001
Amaurosis fugax	3446 (5.6)	1007 (5.3)	.12	666 (3.5)	179 (3.0)	.10	472 (4.6)	106 (4.0)	.24
TIA	3487 (5.7)	1434 (7.6)	<.01	1224 (6.4)	474 (8.0)	<.001	849 (8.2)	257 (9.8)	.011
Stroke	5160 (8.4)	2508 (13.2)	<.001	1640 (8.6)	731 (12.4)	<.001	1015 (9.8)	395 (15.0)	<.001
Hypertension	55,251 (89.9)	17,345 (91.6)	<.001	17,507 (91.3)	5450 (92.3)	.03	9295 (90.4)	2374 (90.8)	.54
Comorbidity index[a]			<.001			<.001			<.001
0	13,301 (21.6)	2921 (15.4)		2878 (15.0)	631 (10.7)		1132 (11.0)	200 (7.6)	
1	21,425 (34.8)	5855 (30.8)		6098 (31.8)	1655 (28.0)		3026 (29.3)	758 (28.8)	
2	15,871 (25.8)	5329 (28.1)		5306 (27.7)	1676 (28.4)		3026 (29.3)	755 (28.7)	
≥3	10,980 (17.8)	4884 (25.7)		4895 (25.5)	1948 (33.0)		3157 (30.5)	918 (34.9)	
Insurance status			<.001			<.01			.001
Medicare	37,563 (61.0)	12,015 (63.3)		13,723 (71.8)	4318 (73.2)		6555 (63.5)	1745 (66.4)	
Medicaid	1975 (3.2)	721 (3.8)		507 (2.7)	190 (3.2)		442 (4.3)	106 (4.0)	
Military/commercial/ private	21,562 (35.0)	6065 (32.0)		4785 (25.0)	1366 (23.2)		3263 (31.6)	748 (28.4)	
Self-pay	447 (0.7)	172 (0.9)		112 (0.6)	27 (0.5)		67 (0.65)	31 (1.2)	
Ambulatory status			<.001			<.001			<.001
Independent	56,556 (92.0)	16,160 (85.3)		18,608 (98.3)	5615 (96.3)		10.029 (97.6)	2457 (94.2)	
Needs assistance/ wheelchair or bed-bound	4912 (8.0)	2790 (14.7)		313 (1.7)	219 (3.7)		247 (2.4)	152 (5.8)	
Current smoker	15,236 (24.8)	4202 (22.2)	<.001	4107 (21.4)	1149 (19.5)	<.01	2525 (24.4)	613 (23.3)	<.001
Prior ipsilateral CEA	780 (1.3)	347 (1.8)	<.001	2979 (15.6)	576 (9.8)	<.001	2227 (21.6)	296 (11.3)	<.001
Prior ipsilateral CAS	144 (0.2)	63 (0.3)	.02	321 (1.7)	85 (1.4)	.21	584 (5.6)	105 (4.0)	.001
Prior contralateral CEA/CAS	9195 (15.0)	2820 (14.9)	.81	3445 (18.0)	1087 (18.4)	.45	2060 (19.9)	407 (15.5)	<.001
Contralateral occlusion	2429 (4.3)	893 (5.0)	<.001	1615 (8.7)	551 (9.8)	.020	883 (9.7)	250 (10.7)	.15

CAS, Carotid artery stenting; *CEA*, carotid endarterectomy; *pLOS*, prolonged length of stay; *sLOS*, standard length of stay; *TCAR*, transcarotid artery restenting; *TfCAS*, transfemoral carotid artery stenting; *TIA*, transient ischemic attack.
Data are presented as number (%) or median (interquartile range).
Patients who died during the index hospitalization, those who underwent surgery on Saturday or Sunday, and patients transferred from other institutions were excluded from the analysis.
[a]Comorbidity Index: a score of 1 is given for the following comorbidities: history of myocardial infarction, congestive heart failure, diabetes, chronic obstructive pulmonary disease, peripheral arterial disease, cerebrovascular disease (stroke/transient ischemic attack) and a score of 2 if for chronic kidney disease (transplant, dialysis, or creatinine >3 mg/dL).

mortality and stroke/death both on unadjusted and adjusted analysis. Specifically, for TfCAS, pLOS was significantly associated with new-onset stroke at 1 year (hazard ratio [HR], 1.87; 95% confidence interval [CI], 1.18-2.97; $P = .01$) (Table IV).

Predictors of pLOS. On adjusted analysis, TfCAS was associated with decreased LOS compared with CEA (odds ratio [OR], 0.8; 95% CI, 0.77-0.84; $P < .001$) and TCAR (OR, 0.8; 95% CI, 0.73-0.92; $P < .01$).

CEA, TCAR, and TFCAS. MAEs were the most common drivers of pLOS after CEA (OR, 6.5; 95% CI, 5.9-7.3), TCAR (OR, 11.1; 95% CI, 9.3-13.2), and TFCAS (OR, 13.1; 95% CI, 9.6-17.9). The occurrence of a MAE increased LOS by an average of 2 days. Postprocedural hypotension was associated with nearly three times the odds of pLOS after CEA (OR, 2.8; 95% CI, 2.5-3.1), five times the odds after TCAR (OR, 5.3; 95% CI, 4.7-6.0), and 6.5 times the odds after TfCAS (OR, 6.5; 95% CI, 5.4-7.9). Postprocedural hypertension was also associated with increased odds of pLOS

Table II. Intraoperative variables in carotid endarterectomy (*CEA*), transcarotid artery revascularization (*TCAR*), and transfemoral carotid artery stenting (*TfCAS*)

	CEA (n = 80,566)			TCAR (n = 25,087)			TFCAS (n = 12,972)		
	sLoS (76.4%)	pLoS (23.6%)	*P* value	sLoS (76.4%)	pLoS (23.6%)	*P* value	sLoS (79.7%)	pLoS (20.3%)	*P* value
Anatomic high risk	5561 (9.0)	1952 (10.3)	<.001	9522 (49.7)	2466 (41.7)	<.001	4972 (48.1)	988 (37.6)	<.001
Preoperative medications									
Dual antiplatelets	18,643 (30.3)	6562 (34.6)	<.001	15,839 (82.6)	4749 (80.4)	<.001	7711 (74.6)	1902 (72.3)	.02
Anticoagulation	6908 (11.2)	2729 (14.4)	<.001	2642 (13.8)	994 (16.8)	<.001	1379 (13.3)	401 (15.3)	.01
Annual physicians' case volume			<.001			<.001			.22
Low	18,721 (30.4)	7377 (38.9)		6404 (33.4)	2169 (36.7)		3638 (35.2)	890 (33.8)	
Medium	20,861 (33.9)	6007 (31.6)		6265 (32.7)	1895 (32.1)		3307 (32.0)	832 (31.6)	
High	21,995 (35.7)	5605 (29.5)		6508 (33.9)	1846 (31.2)		3396 (32.8)	909 (34.6)	
Center volume			<.001			<.001			.02
Low	20,317 (33.0)	6644 (35.0)		6387 (33.3)	2094 (35.4)		3693 (35.7)	874 (33.2)	
Medium	20,387 (33.1)	6283 (33.1)		6381 (33.3)	2012 (34.0)		3237 (31.3)	891 (33.9)	
High	20,873 (33.9)	6062 (31.9)		6409 (33.4)	1804 (30.5)		3411 (33.0)	866 (32.9)	
Day of procedure									<.001
Friday	9701 (15.7)	3587 (18.9)	<.001	3206 (16.7)	1195 (20.2)	<.001	1575 (15.2)	504 (19.2)	
CEA technique			.08		—				
Conventional	53,996 (87.9)	16,526 (87.4)							
Eversion	7433 (12.1)	2376 (12.6)							
Patch use	54,397 (89.0)	16,360 (86.7)	<.001						
Protamine	46,468 (75.6)	13,780 (72.7)	<.001	16,785 (88.6)	5022 (86.1)	<.001	1389 (15.7)	370 (16.2)	.56
Intraoperative shunting	29,249 (47.6)	8728 (46.1)	<.001		—			—	
Drain use	22,699 (36.9)	7869 (41.5)	<.001						
Pre-stent dilatation		—		16,527 (89.8)	4.954 (87.2)	<.001	5860 (70.5)	1544 (71.4)	.41
Post-stent dilatation				7288 (38.3)	2601 (44.6)	<.001	7096 (70.0)	1861 (71.6)	.10

pLOS, Prolonged length of stay; *sLOS*, standard length of stay.
Data are presented as number (%).

(CEA: OR, 2.8; 95% CI, 2.5-3.1; TCAR: OR, 1.7; 95% CI, 1.5-2.0; and TfCAS: OR, 2.4; 95% CI, 1.95-2.9; all $P < .001$).

Other common predictors of pLOS for all three procedures included older age, female sex, non-White race, symptomatic status, higher comorbidity index, nonambulatory status, and surgeries done on Friday. Patients with a comorbidity index of ≥3 had the highest likelihood of having a pLOS (CEA: OR, 1.6; 95% CI, 1.5-1.8; TCAR: OR, 1.85; 95% CI, 1.7-2.1; TfCAS: OR, 1.7; 95% CI, 1.3-2.2; all $P < .001$).

Procedure-specific factors. For CEA, factors associated with an increased LOS included Medicaid insurance and self-payment/lack of insurance (OR, 1.25; 95% CI, 1.1-1.4 and OR, 1.4; 95% CI, 1.1-1.8, respectively), contralateral carotid artery occlusion (OR, 1.3; 95% CI, 1.2-1.4), use of dual antiplatelet therapy (OR, 1.1; 95% CI, 1.1-1.2), anticoagulation (OR, 1.3; 95% CI, 1.2-1.4), and drain use (OR, 1.2; 95% CI, 1.1-1.3). On the other hand, factors associated with decreased LOS included surgeons with higher case volumes (>11 cases/year) (OR, 0.6; 95% CI, 0.56-0.7), protamine (OR, 0.9; 95% CI, 0.8-0.99), and patch use (OR, 0.8; 95% CI, 0.7-0.9) (Table V).

pLOS after TCAR was significantly associated with Medicaid insurance (OR, 1.4; 95% CI, 1.1-1.7), anticoagulation use (OR, 1.2; 95% CI, 1.1-1.3), and post-stent dilation (OR, 1.2; 95% CI, 1.1-1.3). On the other hand, a history of prior ipsilateral CEA (OR, 0.7; 95% CI, 0.6-0.8), use of dual antiplatelet therapy (OR, 0.9; 95% CI, 0.8-0.97), procedures performed by surgeons with >6 cases/year (OR, 0.75; 95% CI, 0.6-0.9), and protamine use (OR, 0.8; 95% CI, 0.7-0.9) were associated with decreased LOS.

For TFCAS, self-payment or lack of insurance coverage (OR, 2.9; 95% CI, 1.4-5.8) was a predictor of pLOS. On the contrary, history of prior ipsilateral CEA (OR, 0.6; 95% CI, 0.5-0.7), or contralateral carotid artery revascularization (OR, 0.8; 95% CI, 0.7-0.9) were associated with decreased LOS.

DISCUSSION

In the ever-increasing landscape of health care expenses under a value-based care model, certain metrics

Table III. In-hospital and 1-year outcomes

	CEA			TCAR			TFCAS		
	sLoS	pLoS	*P* value	sLoS	pLoS	*P* value	sLoS	pLoS	*P* value
In-hospital outcomes									
TIA	77 (0.1)	228 (1.2)	<.001	23 (0.1)	84 (1.4)	<.001	26 (0.25)	71 (2.7)	<.001
Stroke	22 (0.04)	323 (1.7)	<.001	15 (0.1)	114 (1.9)	<.001	9 (0.1)	94 (3.8)	<.001
MI	32 (0.05)	391 (2.1)	<.001	11 (0.1)	102 (1.7)	<.001	8 (0.1)	31 (1.2)	<.001
Cranial nerve injury	1101 (1.8)	769 (4.1)	<.001	19 (0.1)	26 (0.5)	<.001	-	-	
Bleeding	171 (0.3)	564 (3.0)	<.001	60 (0.3)	132 (2.2)	<.001	7 (0.1)	30 (1.1)	<.001
RTOR	195 (0.3)	965 (5.1)	<.001	57 (0.3)	134 (2.3)	<.001	4 (0.04)	33 (1.3)	<.001
Reperfusion	9 (0.01)	35 (0.2)	<.001	48 (0.25)	57 (0.96)	<.001	25 (0.2)	34 (1.3)	<.001
CHF	16 (0.03)	182 (0.96)	<.001	3 (0.02)	67 (1.1)	<.001	5 (0.1)	24 (0.9)	<.001
Dysrhythmia	-	-		71 (0.4)	278 (4.7)	<.001	39 (0.4)	124 (4.7)	<.001
SSI	4 (0.01)	17 (0.1)	<.001	2 (0.01)	1 (0.02)	.55	0	1 (0.04)	.20
Restenosis/occlusion	—	—		3 (0.02)	28 (0.5)	<.001	5 (0.1)	14 (0.6)	<.001
Pseudoaneurysm	—	—		0	8 (0.1)	<.001	18 (0.2)	40 (1.6)	<.001
MAEs[a]	1595 (2.6)	2974 (15.7)	<.001	243 (1.3)	772 (13.1)	<.001	134 (1.3)	418 (15.9)	<.001
Postprocedural hypotension	5177 (8.4)	3341 (17.6)	<.001	2225 (11.6)	2342 (39.7)	<.001	1090 (10.6)	1131 (43.1)	<.001
Postprocedural hypertension	9621 (15.6)	6302 (33.3)	<.001	2396 (12.5)	1000 (17.0)	<.001	777 (7.5)	337 (12.8)	<.001
Operative time, minutes	112.1 (0.17)	126.2 (0.36)	<.001	69.0 (0.44)	77.1 (1.3)	<.001	63.4 (0.39)	72.6 (0.86)	<.001

CAS, Carotid artery stenting; *CEA*, carotid endarterectomy; *CHF*, congestive heart failure; *MAE*, major adverse event; *MI*, myocardial infarction; *pLOS*, prolonged length of stay; *RTOR*, return to operating room; *sLOS*, standard length of stay; *SSI*, surgical site infection; *TCAR*, transcarotid artery restenting; *TfCAS*, transfemoral carotid artery stenting; *TIA*, transient ischemic attack.
Data are presented as number (%) or mean (standard error).
[a]MAEs include any of the following in-hospital events: stroke, TIA, MI, CHF, dysrhythmia, reperfusion syndrome, bleeding requiring intervention, stenosis/occlusion requiring intervention, RTOR, pseudoaneurysm formation, cranial nerve injury, and SSIs.

Table IV. Adjusted 1-year outcomes in patients with prolonged length of stay (pLOS) vs those with a length of stay (LOS) of ≤1 day after the index procedure

	CEA		TCAR		TFCAS	
	HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Death	1.64 (1.49-1.82)	<.001	1.56 (1.35-1.80)	<.001	1.33 (1.08-1.64)	.01
Stroke	1.28 (0.99-1.64)	.06	0.75 (0.43-1.33)	.33	1.87 (1.18-2.97)	.01
Stroke/death	1.54 (1.38-1.72)	<.001	1.39 (1.15-1.67)	.001	1.58 (1.25-1.99)	<.001

CAS, Carotid artery stenting; *CEA*, carotid endarterectomy; *CI*, confidence interval; *HR*, hazard ratio; *TCAR*, transcarotid artery restenting; *TfCAS*, transfemoral carotid artery stenting.
Outcomes adjusted for age, gender, race, comorbidity index, symptomatic and ambulatory status, insurance status, contralateral occlusion, and physician/center volume.

like LOS and readmission goals have garnered considerable focus and have become measurable indicators of quality outcomes. However, the issue of pLOS following carotid revascularization persists, impacting the financial viability of the procedure for hospitals.[2] Our study shows that nearly 23% of patients stayed in the hospital for more than 1 day after undergoing CEA, TfCAS, or TCAR. Specifically, 13.8% of all patients stayed for 2 days, 4% for 3 days, and 5.4% for ≥4 days. TfCAS was associated with slightly decreased pLOS (20.3%) compared with CEA and TCAR (23.6%), respectively. Overall, pLOS was more prevalent in symptomatic patients compared with asymptomatic patients (30.9% vs 22.4%; $P < .001$), as well as in procedures with at least one major complication compared with uncomplicated cases (67.9% vs 20.8%; $P < .001$).

In addition to the substantial loss of revenue for health care systems caused by longer hospitalizations, pLOS can also be associated with worse post-discharge outcomes. Our analysis showed higher rates of 1-year mortality and stroke/death associated with pLOS (Table IV). A systematic review conducted by Wiseman et al on general and vascular readmission revealed that pLOS is a predictor of readmission in 69% of reporting studies.[11] This can

Table V. Predictors of prolonged length of stay (pLOS) (defined as > 1 day) after different carotid revascularization techniques

	CEA (c-statistic 72.9%)		TCAR (c-statistic 75.1%)		TFCAS (c-statistic 78.6%)	
	OR	*P* value	OR	*P* value	OR	*P* value
Age, years	1.02 (1.01-1.02)	<.001	1.02 (1.02-1.03)	<.001	1.03 (1.02-1.04)	<.001
Female gender	1.32 (1.27-1.37)	<.001	1.40 (1.30-1.50)	<.001	1.36 (1.19-1.54)	<.001
Non-White race	1.54 (1.37-1.74)	<.001	1.39 (1.23-1.57)	<.001	1.30 (1.07-1.58)	.01
Insurance (reference = Medicare)						
Medicaid	1.25 (1.10-1.42)	<.01	1.37 (1.08-1.73)	.01	1.18 (0.83-1.68)	.35
Private	1.02 (0.95-1.08)	.60	1.11 (0.99-1.24)	.06	1.10 (0.94-1.29)	.24
Self-pay	1.41 (1.11-1.79)	.01	0.91 (0.54-1.53)	.71	2.88 (1.41-5.85)	<.01
Symptomatic status						
Amaurosis fugax	0.94 (0.86-1.02)	.14	0.85 (0.70-1.03)	.09	0.79 (0.58-1.08)	.14
TIA	1.26 (1.15-1.38)	<.001	1.11 (0.96-1.27)	.15	1.07 (0.87-1.33)	.50
Stroke	1.51 (1.39-1.62)	<.001	1.46 (1.31-1.64)	<.001	1.33 (1.10-1.61)	<.01
Comorbidity index[a] (reference = 0)						
1	1.11 (1.05-1.17)	<.001	1.25 (1.13-1.39)	<.001	1.33 (1.02-1.72)	.03
2	1.30 (1.22-1.38)	<.001	1.46 (1.31-1.64)	<.001	1.34 (1.05-1.71)	.02
≥3	1.64 (1.52-1.76)	<.001	1.85 (1.66-2.06)	<.001	1.74 (1.35-2.25)	<.001
Ambulatory status (reference = independent)						
Dependent[a]	1.65 (1.55-1.76)	<.001	2.07 (1.61-2.66)	<.001	2.62 (1.73-3.98)	<.001
Prior ipsilateral CEA	1.35 (1.17-1.57)	<.001	0.72 (0.64-0.81)	<.001	0.55 (0.46-0.67)	<.001
Prior contralateral CEA/CAS	-		-		0.79 (0.66-0.94)	.01
Contralateral occlusion	1.27 (1.16-1.38)	<.001	1.12 (0.99-1.26)	.06	1.11 (0.90-1.35)	.32
Preoperative medications						
Dual antiplatelet therapy	1.14 (1.08-1.21)	<.001	0.86 (0.77-0.97)	.01	0.95 (0.81-1.12)	.56
Anticoagulation	1.30 (1.22-1.39)	<.001	1.16 (1.05-1.28)	<.01	1.13 (0.96-1.33)	.15
Surgeon procedural volume (reference = low)						
Medium	0.72 (0.65-0.80)	<.001	0.85 (0.76-0.95)	<.01	0.91 (0.75-1.09)	.30
High	0.64 (0.56-0.73)	<.001	0.75 (0.64-0.89)	<.01	0.98 (0.79-1.22)	.88
Surgery day (reference = Monday-Thursday)						
Friday	1.28 (1.19-1.37)	<.001	1.34 (1.21-1.49)	<.001	1.35 (1.15-1.59)	<.001
Procedural variables						
Protamine	0.90 (0.81-0.99)	.04	0.80 (0.71-0.91)	<.01		
Drain use	1.17 (1.05-1.31)	.01	-			
Patch use	0.83 (0.73-0.94)	<.01	-			
Post stent dilatation	-		1.20 (1.10-1.31)	<.001	1.05 (0.89-1.25)	.54
Postoperative factors						
MAEs	6.53 (5.87-7.26)	<.001	11.1 (9.28-13.2)	<.001	13.1 (9.61-17.9)	<.01
Hypotension	2.80 (2.51-3.11)	<.001	5.31 (4.68-6.01)	<.001	6.52 (5.39-7.88)	<.001
Hypertension	2.80 (2.53-3.09)	<.001	1.73 (1.50-2.00)	<.001	2.39 (1.95-2.93)	<.001

CAS, Carotid artery stenting; *CEA*, carotid endarterectomy; *CI*, confidence interval; *OR*, odds ratio; *TCAR*, transcarotid artery restenting; *TfCAS*, transfemoral carotid artery stenting; *TIA*, transient ischemic attack.
[a]Needing assistance, wheelchair or bed-bound.

be attributed to the fact that patients with pLOS usually have more medical comorbidities, are more prone to complications, and, consequently, are likely to develop additional post-discharge issues. Alternatively, these patients might be discharged before their complications have completely resolved, or the discharge efforts designed to care for the complications are not adequate, leading to readmission.[11-14] The present study identifies several risk factors, including multiple modifiable factors, that were found to predict an increase in LOS beyond 1 day. Notably, LOS was most prolonged in patients experiencing MAEs, which, in this study, encompassed neurological complications (such as stroke/TIA, reperfusion syndrome, cranial nerve injury), cardiac complications

(MI, congestive heart failure, dysrhythmia), as well as interventions for bleeding, return to the operating room, surgical site infection, restenosis/occlusion, or pseudoaneurysm formation. MAEs emerged as the primary drivers of pLOS across all three procedures: CEA (OR, 6.5; 95% CI, 5.9-7.3), TCAR (OR, 11.1; 95% CI, 9.3-13.2), and TfCAS (OR, 13.1; 95% CI, 9.6-17.9). On average, the occurrence of at least one major complication increased LOS by 2 days (95% CI, 2.0-2.4). Additionally, postoperative hemodynamic instability, defined as any hypotension/hypertension requiring continuous intravenous infusion of vasoactive medication for more than 15 minutes or multiple doses of bolus vasoactive medication, was also associated with pLOS. Therefore, focusing on mitigating postoperative complications, such as MAEs and hemodynamic instability, presents an opportunity for modifiable risk reduction and can significantly reduce morbidity, mortality, and LOS after carotid procedures.[1-3]

Most preoperative patient characteristics that contribute to LOS are typically non-modifiable; however, they play a crucial role in predicting LOS and can be utilized for preoperative risk stratification and discharge planning.[1,15-17] In our study, these factors included older age, female sex, non-White race, insurance status, symptomatic presentation, non-ambulatory status, presence of contralateral carotid artery occlusion, and a higher comorbidity index. One possible explanation for the association between Medicaid coverage and self-payment with increased LOS is limited access to health care and higher prevalence of medical comorbidities among the Medicaid and uninsured patients, which increases the likelihood of complications. A study from VQI showed that Medicaid and uninsured patients were more likely to require urgent CEA and have more postoperative complications, in part because of poor preoperative medical optimization.[18] Others have attributed pLOS among Medicaid beneficiaries undergoing CEA or CAS to patients' factors and outcomes and institutional issues and care pathways. For instance, pLOS in this patient population can be related to higher intensive care unit utilization for blood pressure stabilization secondary to inadequate preoperative medication optimization or compliance, or underappreciated preoperative poor functional status as well as to lack of social support or transportation.[7] In terms of symptomatic presentation, stroke was a more significant contributor to LOS compared with TIA and amaurosis fugax. Specifically, if a stroke occurred 30 days prior to presentation, it was associated with an almost four times increased odds of pLOS (OR, 4.0; 95% CI, 3.5-4.5; $P < .001$). A comorbidity index was used in this study to evaluate the effect of multiple comorbid conditions. This is because vascular patients tend to have multiple comorbidities, and thus small individual risks begin to add up to clinically relevant risk of longer LOS when they are present in the same patient.[8] Patients with a comorbidity index of ≥3 had twice the likelihood of experiencing pLOS after all three procedures (CEA: OR, 1.6; 95% CI, 1.5-1.8; TCAR: OR, 1.85; 95% CI, 1.7-2.1; TFCAS: OR, 1.7; 95% CI, 1.3-2.25; all $P < .001$). Non-ambulatory functional status was identified as another predictor of pLOS. Patients with a dependent functional status were previously shown to have higher mortality, longer operative times, a higher incidence of unplanned reoperation, postoperative pneumonia, and LOS of ≥3 days after CEA compared with functionally independent patients.[19] In a study by Kuo et al, poor functional status demonstrated a stronger predictive power than the modified frailty index and was associated with a 48% increase in the odds of 30-day death/stroke after CAS.[20] Female sex, congestive heart failure, and chronic obstructive pulmonary disease have been reported by other studies as significant contributors to pLOS.[1,8,20,21] Besides those factors, Ross et al found that patients with insulin-dependent diabetes, coronary artery disease, hypertension, and increasing American Society of Anesthesiologists class were also at higher risk of postoperative LOS >1 day.[8]

In the present study, a history of prior ipsilateral CEA was associated with increased LOS after CEA, but decreased LOS after TCAR and TfCAS. Ideally, management of recurrent carotid restenosis following CEA or CAS should be individualized.[22] Arhuidese et al reported higher mortality, perioperative cranial nerve injuries, and local complications but similar stroke and MI with redo CEA compared with TfCAS in patients with prior ipsilateral CEA.[23] A significantly lower odds of in-hospital stroke, MI, stroke/TIA has been shown with TCAR compared with redo-CEA.[24] On the other hand, no difference was observed between CEA and CAS in patients with prior ipsilateral CAS.[25] Before offering carotid intervention to functionally dependent patients and those with multiple comorbidities, it is important to carefully assess the risk-benefit ratio. Additionally, implementing outpatient preoperative evaluation, optimizing patient comorbidities, and utilizing these preoperative predictors in identifying "high-risk" individuals could be beneficial in reducing the risk of rehospitalization and post-discharge complications.[3,26,27]

The use of preoperative dual antiplatelets (DAPTs) and anticoagulation was associated with a pLOS after CEA, likely due to the increased risk of bleeding complications associated with these drugs. The evidence on the association between DAPT and the risk of bleeding after CEA is conflicting. Some studies showed no increased risk of hemorrhagic complications in patients on DAPT,[28,29] whereas others reported an increased risk of neck hematoma and reoperation for bleeding compared with aspirin monotherapy.[30-33] In our data, the crude rates of postoperative bleeding and reoperation after CEA were higher in patients receiving DAPT (1.2% vs 0.8%; $P < .001$ and 1.7% vs 1.3%; $P = .003$, respectively) and those maintained on preoperative anticoagulation (1.1% vs

0.9%; $P = .03$ and 1.7% vs 1.4%; $P = .05$, respectively). Increased LOS was also observed in patients undergoing TCAR and receiving preoperative anticoagulation. In contrast, the use of DAPT with TCAR and TfCAS was shown to be associated with a reduction in LOS. Current guidelines recommend DAPT in the perioperative period after CAS and specifically in those undergoing TCAR due to its significant association with stroke reduction and maintenance of stent patency.[34,35] Among the operative variables associated with decreased LOS in CEA and TCAR, intraoperative protamine use has been shown to be beneficial. Heparin reversal with protamine after CEA and TCAR reduces the incidence of neck hematoma without increasing the risk of thrombotic complications.[36,37]

Clinical practices vary widely among vascular surgeons and can have various effects on postoperative complications and LOS. In our analysis, patch use was associated with decreased LOS, whereas drain use had the opposite correlation. CEA patch closure has been emphasized by several quality initiatives as it decreases postoperative bleeding requiring reoperation and 1-year ipsilateral neurologic events, as well as restenosis or occlusion.[38] On the other hand, studies using the VQI database have shown that drain placement after CEA does not reduce return to the operating room for bleeding, perioperative stroke, or death but does increase LOS.[39] In our study, 2372 operators performed CEA. Of those, 50% selectively placed a drain, 17.4% routinely did, and 32.4% never placed a drain for CEA.

Avoiding post-dilation where applicable during CAS could also be beneficial in reducing perioperative complications. Post-stent dilatation was associated with a 20% increase in the odds of pLOS after TCAR (OR, 1.20; 95% CI, 1.10-1.31), but not after TfCAS. Studies on post-stent dilatation during CAS have shown an increase in hemodynamic instability and neurological complications up to 30 days.[40,41] Thus, some authors have suggested that a safer threshold to prompt post dilation would be a residual stenoses above current practiced standard and may reduce unnecessary complications.[40]

Another predictor of reduced LOS is a higher surgeon's volume. Specifically, surgeons performing more than 11 cases of CEA a year and more than 6 TCAR procedures had lower odds of pLOS. These finding align with another study by Ross et al, where surgeon volume was significantly associated with LOS after elective uncomplicated CEA, whereas center volume was not.[8] Surgeries performed on Fridays also tend to have higher LOS compared with those performed from Monday to Thursday. Cheng et al found that asymptomatic CEA performed before the weekend was associated with longer LOS. More importantly, this increase in LOS was not due to higher complications, as there were no differences in perioperative mortality, morbidity, and discharge medication compliance.[42] During the weekend, common barriers contributing to longer LOS include diminished hospital resources and a lack of staffing. To address this issue, a study by Patel et al implemented a process improvement model aimed at increasing the percentage of "by noon discharge" over a 2-year period.[43] The study demonstrated a significant decrease in LOS by 0.28 days ($P < .05$) with similar readmission rates.[43] Considering these findings, it may be beneficial for individual surgeons and surgery teams to focus on earlier weekend rounding, preparation of discharge paperwork before the weekend, and improved staffing to increase profitability without affecting readmission rates.[43-45]

Although our analysis represents a national sample of almost 118,625 patients, there are several limitations to consider. The retrospective nature of the analysis introduces the potential for selection bias. Thus, the predictive models in the study do not establish causality but simply a significant association between several factors and pLOS. Many of the variables found to predict pLOS do not directly affect LOS but are surrogates for increased rates of complications or certain practices that could influence LOS. It is important to note that minor complications such as urinary retention or respiratory complications that may delay discharge are not captured in the data from VQI. Moreover, the length of participation in the VQI and the quality improvement efforts of the participating centers could potentially affect the generalizability of our findings. However, an analysis by Ross et al showed no association between the length of center participation in the VQI and LOS. To improve the generalizability of our findings, a comparison of LOS in VQI vs non-VQI participating centers would be helpful. Additionally, the follow-up period at 1 year is limited to only 60% of the original cohort, and data on readmissions were not available. Another limitation is the lack of hospital details that could provide valuable insights. For example, we do not have information on whether patients were admitted to an intensive care unit, a step-down unit, or a regular floor postoperatively, which could impact the workflow and potentially affect LOS. Other important information not accounted for in our analysis include whether hospitals had an early discharge pathway, whether they are academic or community hospitals, the level of resident involvement in the procedure, and patient social influences. Despite these limitations, the major strengths of this work are that we analyzed data from a large sample of patients and used powerful statistical analysis to identify variables to include in our models. This allowed us to identify several predictors of pLOS after common vascular procedures, which can guide quality improvement efforts to shorten LOS and improve patient outcomes.

CONCLUSION

Up to 23% of patients undergoing carotid revascularization experience a postoperative LOS exceeding 1 day.

Although many factors contributing to pLOS in our patient population are beyond the provider's control, this study has identified several factors associated with increased LOS that can serve as targets for quality improvement initiatives aimed at enhancing care and reducing LOS. Strategies such as identifying patients prone to postoperative complications, optimizing the management of comorbidities, adhering to evidence-based practice guidelines, and improving discharge planning can effectively shorten LOS after carotid revascularization procedures and improve their 1-year survival.

AUTHOR CONTRIBUTIONS

Conception and design: HDA, MS, AG, RLM
Analysis and interpretation: HDA, BL, MPM, MM, MS, VK, JJ, RLM
Data collection: HDA, MM, GW
Writing the article: HDA, BL, RLM
Critical revision of the article: HDA, BLM, MPM, MM, MS, VK, GW, JJ, AG, RLM
Final approval of the article: HDA, BLM, MPM, MM, MS, VK, GW, JJ, AG, RLM
Statistical analysis: HDA, BL, AG, RLM
Obtained funding: Not applicable
Overall responsibility: RLM

DISCLOSURES

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