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Regional variation in patient selection, practice patterns, and outcomes based on techniques for carotid artery revascularization in the Vascular Quality Initiative

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ABSTRACT

Objective: Significant regional variation is known with multiple surgical procedures. This study describes regional variation in carotid revascularization within the Vascular Quality Initiative (VQI).

Methods: Data from the VQI carotid endarterectomy (CEA) and carotid artery stenting (CAS) databases from 2016 to 2021 were used. Nineteen geographic VQI regions were divided into three tertiles based on the average annual volume of carotid procedures performed per region (low-volume: 956 cases [range, 144-1382]; medium-volume: 1533 cases [range, 1432-1589]; and high-volume: 1845 cases [range, 1642-2059]). Patients' characteristics, indications for carotid revascularization, practice patterns, and outcomes (perioperative and 1-year stroke/death) of different revascularization techniques were compared between these regional groups. Regression models that adjust for known risk factors and allow for random effects at the center level were used.

Results: CEA was the most common revascularization procedure (>60%) across all regional groups. Significant regional variation was observed in the practice of CEA such as variability in the use of shunting, drain placement, stump pressure and electroencephalogram monitoring, intraoperative protamine, and patch angioplasty. For transfemoral CAS, high-volume regions had a higher proportion of asymptomatic patients with <80% stenosis (30.5% vs 27.8%) in addition to higher use of local/regional anesthesia (80.4% vs 76.2%), protamine (16.1% vs 11.8%), and completion angiography (81.6% vs 77.6%) during transfemoral carotid artery stenting (TF-CAS) compared with low-volume regions. For transcarotid artery revascularization (TCAR), high-volume regions were less likely to intervene on asymptomatic patients with <80% stenosis (32.2% vs 35.8%) than low-volume regions. They also had a higher proportion of urgent/emergent procedures (13.6% vs 10.4%) and were more likely to use general anesthesia (92.0% vs 82.1%), completion angiography (67.3% vs 63.0%), and poststent ballooning (48.4% vs 36.8%). For each carotid revascularization technique, no significant differences were noted in perioperative and 1-year outcomes between low-, medium-, and high-volume regions. Finally, there were no significant differences in outcomes between TCAR and CEA across the different regional groups. In all regional groups, TCAR was associated with a 40% reduction in perioperative and 1-year stroke/death compared with TF-CAS.

Conclusions: Despite significant variation in clinical practices for the management of carotid disease, no regional variation exists in the overall outcomes of carotid interventions. TCAR and CEA continue to show superior outcomes to TF-CAS across all VQI regional groups. (J Vasc Surg 2023;78:687-94.)

Keywords: Carotid revascularization; Stenting; Endarterectomy; TCAR; Stroke; Death; Regional variation

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Significant regional variation has been identified after multiple surgical procedures.[1-4] Differences in disease burden and diagnostic practices explain only a small degree of regional variation in the use of common surgical procedures.[4] Several studies have suggested that this variation is mainly attributed to differences in physicians' beliefs about surgical indications and incorporation of patients' preferences into treatment decisions.[4-6]

A wide variation in clinical practice for the management of carotid disease has been reported despite clear guidelines from the Society for Vascular Surgery.[7] The examples of this variation include preoperative medical management, the proportion of asymptomatic patients being treated by carotid artery stenting (CAS), and the use of a protection device during CAS.[3] Variation in the use of a patch and protamine during carotid endarterectomy (CEA), as well as length of stay and the use of intravenous vasoactive medications after elective, uncomplicated CEA, has also been reported.[4-6] The introduction of transcarotid artery revascularization (TCAR) has offered a new and effective minimally invasive alternative for the treatment of carotid artery stenosis in high-risk surgical patients.[8-11]

This study aimed to describe contemporary regional variation in baseline patient comorbidities, indications for treatment, intraoperative techniques, and perioperative outcomes based on the technique used for carotid revascularization (TCAR, CEA, and transfemoral CAS [TF-CAS]). We hypothesize that this appraisal can help guide efforts to improve outcomes after carotid revascularization, increase adherence to existing guidelines, and direct further research to define best practices in a field with wide variability among clinical practices.

ARTICLE HIGHLIGHTS

- **Type of Research**: Retrospective review of prospectively collected Vascular Quality Initiative (VQI) data
- **Key Findings:** The analysis of 126,768 carotid interventions in 19 geographical regions participating in the VQI database showed significant regional variation in patient comorbidities and practices of carotid revascularization. No significant regional variation was observed in the outcomes of carotid interventions. Transcarotid artery revascularization is increasingly used for carotid revascularization while demonstrating superior outcomes to transfemoral carotid artery stenting across all VQI regional groups.
- **Take Home Message:** Carotid endarterectomy remains the most used treatment option for carotid revascularization. Significant regional variation exists in clinical practices, underlining important quality improvement opportunities for standardizing management of carotid revascularization and encouraging adherence to societal guidelines.

METHODS

The Society for Vascular Surgery Vascular Quality Initiative (VQI) was used to identify consecutive carotid revascularization procedures from participating hospitals across the United States between 2016 and September 2021. The VQI is a national clinical registry set up as collaboration between regional quality groups. More information about the VQI can be found at www.vascularqualityinitiative.org. The VQI Research Advisory Committee and the institutional review board at Indiana University approved this study (proposal number: 4613). The need for informed consent was waived because of the retrospective nature of the study and the use of deidentified data. Patients who underwent TF-CAS and TCAR without a protection device were excluded. TCARs performed using a distal embolic protection device and TF-CAS performed with flow reversal were also excluded. Moreover, procedures for tandem, traumatic, or dissection lesions were excluded as these are less common and usually associated with worse outcomes. We also excluded patients with more than one stented lesion and those who underwent concomitant procedures during CEA.

Variables. Nineteen geographical regions were identified and included in the study. In VQI, each geographical region is defined by a unique number. Each VQI center retains the same number across all registries. For each region, we calculated the average number of carotid interventions performed per year. We then calculated tertiles using our statistical software that divided the dataset into three equal parts based on the average number of carotid procedures performed in each region, so that each group contains a third of the population: low-volume group (mean 956 cases, range: 144-1382), medium-volume group (mean 1533 cases, range: 1432-1589), and high-volume group (mean 1845 cases, range: 1642-2059). Preoperative variables included patients' demographics (age, sex, and race); symptomatic status (defined as the presence of ipsilateral cortical or ocular symptoms such as amaurosis fugax, hemispheric transient ischemic attack, or stroke up to 6 months before the intervention); ambulatory status (ambulates independently, needs assistance or uses a wheelchair, or bedridden); smoking history; medical comorbidities including hypertension, coronary artery disease, congestive heart failure, diabetes mellitus, chronic obstructive pulmonary disease, and chronic kidney disease; and dialysis. Prior cardiovascular procedures included a history of prior coronary artery bypass grafting, percutaneous coronary intervention, CEA, or CAS. Preoperative medication included platelet inhibitor therapy (aspirin, clopidogrel, prasugrel, ticlopidine, and ticagrelor), β-blockers, statins, anticoagulants, and angiotensin-converting enzyme inhibitors if taken within 36 hours of the procedure. Other variables included American Society of Anesthesiologists classification, presence of anatomic high-risk criteria as defined by the Center for Medicaid and Medicare Services,[12] preoperative stress testing, and elective cases. Operative variables included type of anesthesia, use of protamine, pre- and poststent angioplasty during CAS, use of patch angioplasty, intraoperative shunting, drain placement, neuromonitoring technique, and completion imaging. Center-specific case volumes were calculated as follows; for each of the 694 centers included, the average annual number of carotid cases performed was calculated. We then divided these centers into three groups based on their annual number of carotid interventions performed: low-volume centers (n = 532, mean number of cases/y: 32.8, range: 1-54.8), medium-volume centers (n = 109, mean number of cases/y: 76.8, range: 55-104.3), and high-volume centers (n = 53, mean number of cases/y: 147, range: 106-304.7).

Outcomes. The primary outcomes were a composite of perioperative and 1-year stroke or death. Secondary outcomes included the individual outcomes of in-hospital stroke, death, myocardial infarction (MI), and stroke/death/MI. Strokes were defined as either ipsilateral or contralateral, cortical or vertebrobasilar, and as ischemic or hemorrhagic. This was determined clinically by postoperative neurological symptoms, with or without imaging confirmation. MI included both clinical MI and troponin-positive-only MI. One-year mortality was determined through linkage to the Social Security Death Index.

Statistical analysis. For each type of carotid revascularization, preoperative, intraoperative, and postoperative variables were compared between low-, medium-, and high-volume regional groups. Comparison of continuous variables among the three regional groups was performed using the analysis of variance, Mann-Whitney, or Kruskal-Wallis tests as appropriate. Comparison of categorical variables was performed using χ^2 tests. Multivariable logistic regression was used to evaluate perioperative outcomes while adjusting for patients' baseline characteristics. This was done based on clinical judgment and the results of bivariate analysis. All perioperative end points discussed had <5% of missing data with minimal regional differences for the proportion of missing data. Separate stepwise backward and forward logistic regression analyses were used to select the variables to be retained in the final models. For the stepwise backward model, variables with a $P > .20$ were removed. For the forward models, those with a P value of $<.20$ were entered. A set of the following variables, not necessarily all, were included in different models: age, sex, race, symptomatic and ambulatory status, hypertension, diabetes, prior coronary artery bypass grafting/percutaneous coronary intervention, congestive heart failure, CAS, chronic obstructive pulmonary disease, diabetes mellitus, smoking history, prior ipsilateral CAS or CEA, American Society of Anesthesiologists classification, preoperative medication use (aspirin and other antiplatelets, β-blockers, anticoagulant, and statin), and presence of anatomic high-risk criteria. The C statistic and Hosmer-Lemeshow goodness-of-fit tests were used to assess the discrimination and calibration of the multivariable models, respectively. Observations were clustered with respect to centers to reduce the bias from hospital-level factors and to account for intergroup correlation. One-year analysis was performed using Kaplan-Meier time-to-event analysis, censoring patients lost to follow-up. Comparisons were made using log-rank tests and Cox proportional hazard models for the unadjusted and the adjusted analyses, respectively.

Finally, to evaluate whether the discrepancy in outcomes between different carotid interventions was different based on the regional group, the interaction between procedure type (CEA, TF-CAS, and TCAR) and regional group (low-, medium-, and high-volume) was evaluated by forcing the interaction terms in the multivariable regression model. The adjusted odds of in-hospital stroke/death and the hazard ratios of 1-year stroke/death were calculated using postestimation commands, respectively. A P value of $<.05$ was considered significant. Stata version 12.0 (StataCorp) was used for all analyses.

RESULTS

A total of 126,768 procedures were included in the analysis: CEA 88,367, TF-CAS 16,298, and TCAR 22,103. There were 19 deidentified regional groups that were divided into three groups based on the average annual number of carotid procedures performed in each region. Low-volume groups constituted 11 regions (274 centers) with a mean annual case volume of 956 carotid procedures (range: 144-1382), medium-volume groups constituted 5 regions (230 centers) with an average of 1533 cases a year (range: 1432-1589), and high-volume groups constituted 3 regions (190 centers) with an annual average of 1845 procedures (range: 1642-2059). The average annual number of carotid procedures performed in different VQI regional groups is shown in Fig 1. It is important to note that each regional group consists of multiple centers with different case volumes. In all three regional groups, the vast majority of centers performed an average number of <55 carotid interventions per year (77.4% of high-volume regions, 73.9% of medium-volume regions vs 78.4% of low-volume regions). On the other hand, high-volume centers (those performing between 106 and 305 cases/y) were present in 5.1% of

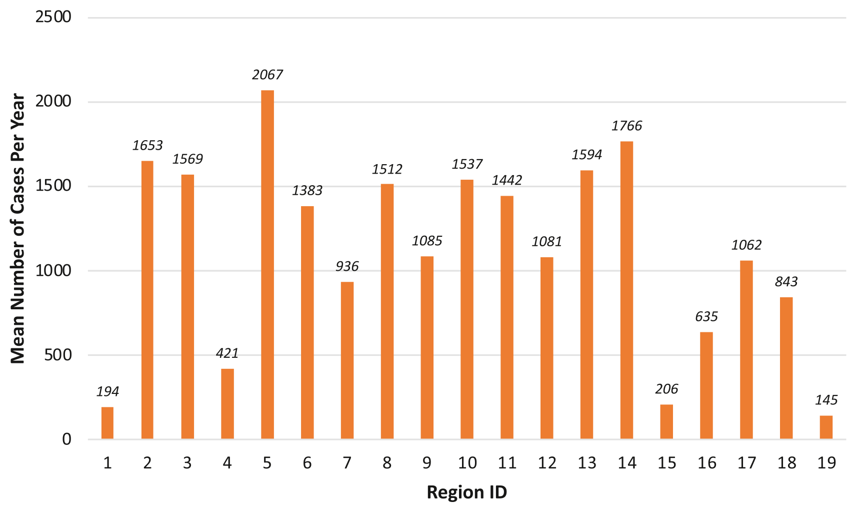

Fig 1. Average annual number of carotid interventions performed in different Vascular Quality Initiative (VQI) regional groups.

regions classified as low-volume, 10% of medium-volume, and in only 8.4% of high-volume regions.

Overall, there has been an increase in the utilization of TCAR since its introduction (1.5%-26%). On the other hand, the use of CEA has significantly decreased from 83.8% of all carotid interventions performed in 2016 to 60.5% in 2021. TF-CAS had less significant changes (Fig 2). The individual regions in VQI showed similar trends with some inter-regional variation. Despite significant regional variation in the number and trends of carotid procedures performed, CEA remained the most performed procedure in all regions ranging from 61.9% to 100%. This was followed by TCAR (range: 0%-28.1%) and TF-CAS (range: 0%-20.3%).

Baseline characteristics. The differences in patients' baseline characteristics across the different regional groups were further stratified based on the type of carotid procedure performed and were recorded in Supplementary Table I, online only. Many variables were statistically different across the low-, medium-, and high-volume regional groups; however, some of these differences were not clinically relevant. High-volume regions were more likely to perform TF-CAS on asymptomatic patients with less than 80% carotid artery stenosis (30.5% vs low-volume: 27.8%, and medium-volume: 25.3%, $P < .001$). On the other hand, TCAR was less likely to be performed for asymptomatic patients with <80% stenosis in high- vs low- and medium-volume regions (32.2% vs 35.8% and 36.8%, $P < .001$).

Procedural variability. There were significant differences across regions in almost all procedural variables and practice patterns analyzed. This variability was also reflected in all three revascularization methods (Supplementary Tables II and III, online only). Notably, for CEA, differences in the use of protamine, CEA technique (conventional vs eversion), electroencephalogram monitoring, and completion Doppler were noted to be favoring high-volume regions, whereas the use of preoperative stress testing, intraoperative shunting, stump pressures, drain placement and completion duplex, and angiography was more likely to be favored in low- and medium-volume regions.

For TF-CAS, preoperative stress testing, protamine use, and completion angiography were more common in high-volume regions, whereas the use of general anesthesia was more prevalent in low-volume regions. On the other hand, for TCAR, high-volume regional groups had a higher proportion of cases performed under general anesthesia, with completion angiography and post-stent ballooning compared with regions with lower case volumes. Patients in high-volume regions were less likely to undergo preoperative stress testing, receive protamine, or prestent ballooning (Supplementary Table III, online only).

Outcomes. The regional volume was not significantly associated with postoperative outcomes (Table). After adjusting for baseline patient characteristics, no significant regional variation was observed in terms of in-hospital stroke/death after CEA (high-volume regions vs low-volume regions: odds ratio [OR], 1.01; 95% confidence interval [CI], 0.84-1.21; $P = .94$), TF-CAS (OR, 0.81; 95% CI, 0.62-1.06; $P = .13$), or TCAR (OR, 0.80; 95% CI, 0.61-1.06; $P = .12$). Similarly, the adjusted hazard ratios (HRs) of 1-year stroke/death were not significantly different in high-volume vs low-volume regions after CEA (HR, 1.04; 95% CI, 0.89-1.21; $P = .65$), TF-CAS (HR, 1.01; 95% CI, 0.78-1.28; $P = .97$), or TCAR (HR, 0.94; 95% CI, 0.67-1.32; $P = .73$).

No significant interaction was observed between the three carotid interventions and regional volume in

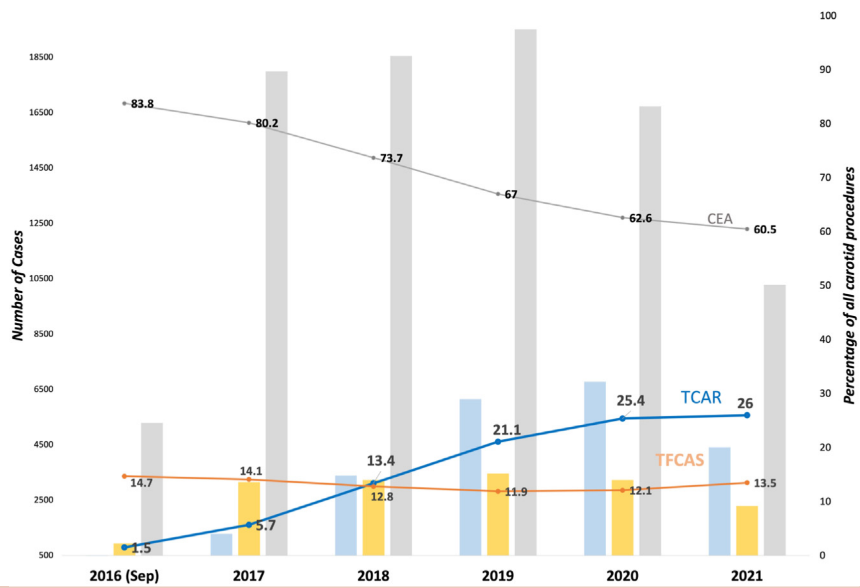

Fig 2. Variation in number and percentage of carotid revascularization procedures. *CEA*, Carotid endarterectomy; *TCAR*, transcarotid artery revascularization; *TF-CAS*, transfemoral carotid artery stenting.

predicting outcomes (Fig 3). Although there seems to be a higher stroke/death after CEA compared with TCAR in low-volume regions, the interaction was nonsignificant (*P*-interaction = .34 and .48, respectively), meaning the outcomes between the two procedures are comparable and do not vary based on the regional group. On the other hand, compared with TF-CAS, TCAR was associated with a reduction of in-hospital stroke/death (OR, 0.62; 95% CI, 0.47-0.83; *P* = .001) and 1-year stroke/death (HR, 0.63; 95% CI, 0.49-0.80; *P* < .001) independent of whether the procedures were performed in low-, medium-, or high-volume groups (*P*-interaction = .90 and .63). Comparing TF-CAS with CEA also showed higher odds of stroke/death after TF-CAS, a finding consistent across the three regional groups.

DISCUSSION

The present study demonstrates significant variation in patient comorbidities and practice patterns of carotid revascularization across the different regions participating in VQI. However, no regional variation was noted in the risk-adjusted outcomes after carotid revascularization. Despite the trend changes in the use of different carotid interventions (Fig 2), CEA remained the most performed carotid revascularization procedure across the different regional groups. The use of TCAR was shown to significantly increase throughout the study's timeframe reflecting better adoption of this safe minimally invasive approach for carotid revascularization. Although no significant differences in perioperative and 1-year stroke/death were observed between TCAR and CEA, TF-CAS continued to show inferior outcomes compared with the two procedures independent of the region.

Regional variation is mainly explained by differences in physician's belief about surgical indications and the preferences of the patient and only to a small degree by variation in patients' comorbidities and diagnostic practices.[5,6] A study by Shean et al[3] in 2017 demonstrated wide variation in clinical practice for the management of carotid disease, including the proportion of asymptomatic patients being treated and the use of a protection device during TF-CAS, preoperative medical management, and the use of a patch and protamine during CEA.

To simplify our description of regional variation, we divided the 19 participating regions in VQI based on the average number of carotid interventions performed yearly. We are aware that each region has several centers that could have either variety of case volumes. Higher hospital and provider volumes are known to be correlated with improved procedural outcomes.[13,14] However, contrary to physician or center case volumes, regional volumes do not impact outcomes of carotid revascularizations or translate into better care due to variation in outcomes of individual centers and physicians within each region. Regional case volumes likely reflect different population sizes, different numbers of VQI-participating centers in that region, and/or increased disease burden, rather than increased experience. In our analysis, overall adjusted outcomes did not differ between regions likely because of variation in outcomes of individual centers and physicians in each region. On the other hand, the variation in practice patterns across

Table. Univariate analysis of perioperative and 1-year outcomes after carotid interventions across different regional groups

	CEA (N = 88,367)				TF-CAS (N = 16,298)				TCAR (N = 22,103)			
	Low	Medium	High	*P* value	Low	Medium	High	*P* value	Low	Medium	High	*P* value
In-hospital outcomes, No. (%)												
Death	125 (0.38)	115 (0.35)	84 (0.38)	.76	98 (1.6)	73 (1.1)	49 (1.3)	.03[a]	48 (0.6)	23 (0.4)	25 (0.35)	.10
Stroke	409 (1.2)	410 (1.2)	282 (1.3)	.84	114 (2.0)	122 (2.1)	80 (2.3)	.72	135 (1.6)	72 (1.2)	101 (1.4)	.13
Myocardial infarction (MI)	200 (0.6)	232 (0.7)	153 (0.7)	.22	39 (0.65)	33 (0.50)	10 (0.27)	.03[a]	50 (0.6)	30 (0.5)	44 (0.6)	.59
Stroke/death	493 (1.5)	487 (1.5)	336 (1.5)	.85	195 (3.3)	180 (2.7)	109 (2.9)	.19	164 (1.9)	90 (1.5)	117 (1.6)	.11
Stroke/death/MI	659 (2.0)	690 (2.1)	466 (2.1)	.46	227 (3.8)	209 (3.2)	117 (3.1)	.08	202 (2.3)	116 (1.9)	155 (2.1)	.16
30-day												
Follow-up rate, %	62.30	66.80	60.90		63.40	67.10	51.40		51	48.90	44.40	
Stroke/death, No. (%)	344 (1.7)	375 (1.7)	229 (1.7)	.93	86 (2.3)	116 (2.6)	40 (2.1)	.38	84 (1.9)	48 (1.6)	60 (1.9)	.56
Stroke/death/MI, No. (%)	443 (2.1)	495 (2.2)	295 (2.2)	.77	106 (2.8)	138 (3.1)	45 (2.4)	.24	104 (2.4)	57 (1.9)	74 (2.3)	.35
One-year												
Follow-up rate, %	58.5	63.2	56.5		56.4	61.6	46.7		43.3	42.8	39.0	
Stroke/death, rate (95% CI)	4.6% (4.3-4.9)	4.5% (4.2-4.8)	4.8% (4.4-5.2)	.454	8.5% (7.6-9.5)	7.2% (6.4-8.0)	8.4% (7.2-9.8)	.11	6.3% (5.6-7.2)	5.4% (4.6-6.5)	5.5% (4.7-6.5)	.125
Stroke/death/MI, rate (95% CI)	5.1% (4.8-5.5)	5.2% (4.9-5.5)	5.4% (5.1-5.9)	.479	9.4% (8.4-10.5)	7.8% (7.0-8.7)	9.0% (7.7-10.4)	.07	7.2% (6.4-8.1)	6% (5.1-7.1)	6.1% (5.2-7.1)	.03[a]

CEA, Carotid endarterectomy; *CI*, confidence interval; *TCAR*, transcarotid artery revascularization; *TF-CAS*, transfemoral carotid artery stenting.
[a]No significant difference observed after multivariable adjustment ($P > .05$).

different regions highlights variation in adherence to societal guidelines.

To focus on the most performed interventions and have a more uniform cohort, the analysis excluded TF-CAS and TCAR procedures that were performed without a protection device, in addition to TF-CAS performed with flow reversal and TCARs performed using distal protection. Interestingly, these excluded cases also varied significantly across different regions.

Our analysis also demonstrated significant regional variation in the percentage of TCAR and TF-CAS performed on asymptomatic patients with less than 80% carotid artery stenosis. These findings highlight the ongoing controversy regarding the management of carotid artery stenosis in asymptomatic patients and its variation based on patient and operator preferences. Although we cannot decipher the specialties of physicians performing those procedures, we know that there is a broad distribution of physician specialties in VQI with less than half being vascular surgeons.[15] In 2021, the US Preventive Services Task Force issued a statement reaffirming the evidence that the harms of screening for carotid artery stenosis in asymptomatic adults outweigh the benefits.[16] Most current national guidelines recommend that asymptomatic patients who have more than 70% narrowing of the carotid artery be evaluated for an intervention.[7] However, given the limited evidence on the benefits of carotid revascularization over contemporary medical management in asymptomatic patients and pending the results of ongoing randomized clinical trials, the management of asymptomatic carotid stenosis will continue to show significant variation.

Other examples of regional variation in practice patterns include discrepancy in the utilization of preoperative stress testing, intraoperative protamine usage, the use of general anesthesia, and completion angiography across which were noted in all three carotid revascularization techniques. These variations highlight several controversial areas that are affected by surgeons' personal preferences and training experience, despite several evidence-based recommendations and clear societal guidelines.[7] For CEA, regional differences in the CEA technique (conventional vs eversion) and in the use of patch angioplasty were also observed. Despite extensive evidence on the benefit of patch angioplasty during CEA in reducing the risk of restenosis and recurrent ipsilateral stroke compared with primary closure, there is still significant variation in practice patterns regarding the use of a patch, instead of primary closure during CEA.[17-22] Similarly, drain placement after CEA

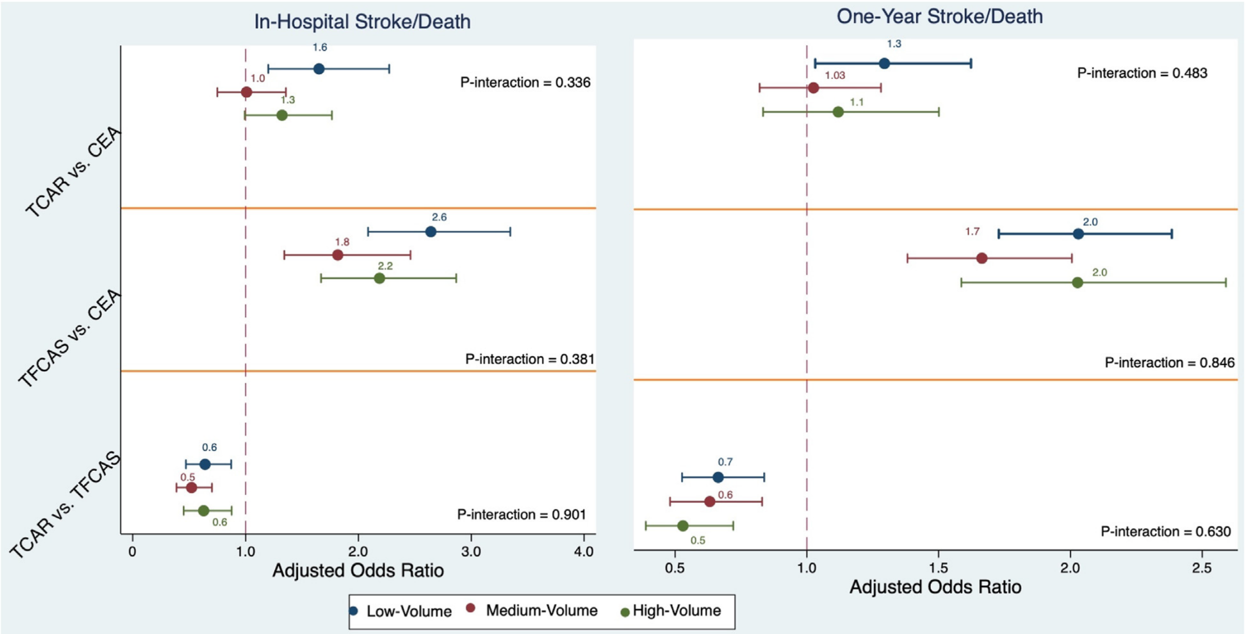

Fig 3. Comparison of the outcomes of different carotid interventions in low-, medium-, and high-volume regional groups. *CEA*, Carotid endarterectomy; *TCAR*, transcarotid artery revascularization; *TF-CAS*, transfemoral carotid artery stenting.

was more common in low-volume regions despite reported evidence that it does not reduce the need to return to the operating room for bleeding nor does it reduce the rates of perioperative stroke or death, and further its known association with increased length of stay.[23] Similar regional variations were also seen with TCAR, specifically in pre- and poststent ballooning (Supplementary Table III, online only). We believe that these differences between high- and low-volume regions are not related to the case volume per se but rather a reflection of variability (nonstandardization) of practice patterns across different regions, which is likely due to differences in physician's skills, training experience, and beliefs about surgical indications. These findings emphasize the importance of directing regional and institutional quality improvement projects toward improved adherence to guidelines, especially in the variables with the greatest variation. Reducing unwarranted practice variation can impact outcomes and increase value within the health care system.[4,5,7]

The study has some limitations that should be taken into consideration. Most notably, it is a retrospective analysis of a prospectively collected database. It has potential issues regarding miscoding and misreporting. However, the VQI conducts annual audits to ensure consecutive procedure entry and to eliminate any inconsistencies between claims data and clinical data entered by each hospital. Within our study, we designated regions as low-, medium-, or high-volume to describe regional variation. Regions designated as being low volume may be more reflective of fewer participating hospitals than the true volume in the region. In addition, the VQI includes only a subset of hospitals providing vascular care and may not be fully representative of national practice patterns. However, our study aims to describe regional variation in carotid revascularization rather than studying the impact of procedural case volumes on outcomes of carotid revascularization or making assumptions about quality of care in particular regions. Moreover, we did not evaluate potential drivers behind these variations such as institutional, or physician- and patient-level factors. Although we can hypothesize about the reasons for variation, it is difficult to do more than speculate on the reasons for variation in practice without feedback from the providers and patients themselves. Follow-up data in the VQI are currently available for only approximately 65% of patients. Finally, this analysis of variation is a step toward identifying opportunities for improving care. Several studies have investigated the association between specific practice patterns and outcomes after carotid revascularization. Although it is beyond the scope of our current analysis, it will be interesting to further identify whether the areas with significant regional variation have worse risk-adjusted outcomes.

CONCLUSIONS

Although no significant regional variation in the overall outcomes of carotid revascularization was observed, this study highlights significant variation in practice patterns, reflecting nonstandardization of these practices and, in some cases, nonadherence to evidence-based guidelines. In all regional groups, TCAR and CEA continue to show superior outcomes to TF-CAS. Future studies should focus on identifying specific areas of practice variation that might lead to worse risk-adjusted outcomes.

AUTHOR CONTRIBUTIONS

Conception and design: HD, RM
Analysis and interpretation: HD, PV, MS, MM, JE, JC, GW, VK, RM
Data collection: HD, PV, MS, MM, VK, RM
Writing the article: HD, PV, RM
Critical revision of the article: HD, PV, MS, MM, JE, JC, GW, VK, RM
Final approval of the article: HD, PV, MS, MM, JE, JC, GW, VK, RM
Statistical analysis: HD, PV, RM
Obtained funding: Not applicable
Overall responsibility: RM

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Supplementary Table I (online only). Baseline characteristics of patients undergoing carotid revascularization in regions with low-, medium-, and high-volume of carotid procedures

	CEA (N = 88,367)				TF-CAS (N = 16,298)				TCAR (N = 22,103)			
Regional case volume	Low (n = 33,285)	Medium (n = 33,096)	High (n = 21,986)	*P* value	Low (n = 5961)	Medium (n = 6610)	High (n = 3727)	*P* value	Low (n = 8688)	Medium (n = 6215)	High (n = 7200)	*P* value
Age ≥75 y												
Female gender	13,088 (39.3)	12,789 (38.6)	8581 (39.0)	.199	2142 (35.9)	2332 (35.3)	1307 (35.1)	.629	3177 (36.6)	2202 (35.4)	2721 (37.8)	.018
Non-White race	3810 (11.5)	2765 (8.4)	2814 (12.8)	<.001	653 (11.0)	669 (10.1)	465 (12.5)	.001	756 (8.7)	580 (9.3)	764 (10.6)	<.001
Insurance				<.001				<.001				<.001
Medicare	19,961 (60.0)	19,201 (58.1)	12,658 (57.6)		3749 (64.2)	3650 (56.9)	2089 (58.4)		6476 (74.7)	4256 (68.6)	4692 (65.6)	
Medicaid	1502 (4.5)	1187 (3.6)	779 (3.5)		361 (6.2)	289 (4.5)	145 (4.1)		339 (3.9)	180 (2.9)	166 (2.3)	
Private	11,819 (35.5)	12,665 (38.3)	8545 (38.9)		1728 (29.6)	2473 (38.6)	1344 (37.6)		1858 (21.4)	1768 (28.5)	2297 (32.1)	
Symptomatic status	9667 (29.0)	9812 (29.6)	6549 (29.8)	.107	2076 (34.8)	2619 (39.6)	1277 (34.3)	<.001	2122 (24.4)	1616 (26.0)	1917 (26.6)	.01
Amaurosis fugax	1964 (5.9)	1954 (5.9)	1307 (5.9)		241 (4.0)	292 (4.4)	141 (3.8)		279 (3.2)	237 (3.8)	261 (3.6)	
TIA	2697 (8.1)	2504 (7.6)	1730 (7.9)		553 (9.3)	749 (11.3)	348 (9.3)		751 (8.6)	506 (8.1)	673 (9.4)	
Stroke	5258 (15.8)	5621 (17.0)	3705 (16.9)		1379 (23.1)	1721 (26.0)	865 (23.2)		1208 (13.9)	970 (15.6)	1105 (15.4)	
Indication				.098				<.001				<.001
Asymptomatic <80%	2646 (8.0)	2619 (7.9)	1681 (7.7)		1498 (27.8)	1426 (25.3)	1017 (30.5)		3009 (35.8)	2246 (36.7)	2266 (32.2)	
Asymptomatic ≥80%	20,950 (63.0)	20,616 (62.4)	13,728 (62.5)		1865 (34.6)	1679 (29.8)	1076 (32.3)		3351 (39.8)	2280 (37.2)	2871 (40.8)	
Symptomatic <50%	381 (1.2)	330 (1.0)	240 (1.1)		68 (1.3)	104 (1.8)	43 (1.3)		101 (1.2)	73 (1.2)	115 (1.6)	
Symptomatic ≥50%	9286 (27.9)	9482 (28.7)	6309 (28.7)		1951 (36.2)	2434 (43.1)	1196 (35.9)		1953 (23.2)	1525 (24.9)	1783 (25.3)	
Independent ambulation	29,140 (87.6)	29,315 (88.8)	19,457 (88.6)	<.001	5622 (94.4)	6204 (94.9)	3507 (95.2)	.317	8312 (95.8)	5794 (96.6)	6862 (96.1)	.186
Hypertension	29,650 (89.2)	29,677 (89.9)	19,866 (90.5)	<.001	5223 (88.3)	5812 (88.6)	3343 (90.5)	.002	7955 (91.6)	5696 (91.7)	6519 (90.6)	.049
Diabetes	12,388 (37.2)	12,084 (36.6)	7995 (36.4)	.083	2345 (39.4)	2543 (38.6)	1510 (40.6)	.116	3389 (39.0)	2403 (38.7)	2724 (37.8)	.310
Coronary artery disease	9063 (27.2)	8890 (26.9)	5932 (27.0)	.652	2824 (47.7)	2826 (43.0)	1788 (48.3)	<.001	4627 (53.3)	3307 (53.2)	3686 (51.2)	.017
Prior CABG/PCI	11,217 (33.7)	11,563 (34.9)	7228 (32.9)	<.001	2194 (36.8)	2402 (36.3)	1427 (38.3)	.137	3450 (39.7)	2542 (40.9)	2841 (39.5)	.194
Congestive heart failure	3857 (11.6)	3965 (12.0)	2628 (12.0)	.217	1063 (17.8)	1050 (15.9)	704 (18.9)	<.001	1645 (18.9)	1115 (18.0)	1122 (15.6)	<.001
COPD	8004 (24.1)	7622 (23.1)	4868 (22.2)	<.001	1667 (28.0)	1652 (25.0)	947 (25.4)	<.001	2400 (27.6)	1587 (25.5)	1677 (23.3)	<.001
CKD	11,217 (34.0)	11,092 (33.8)	7498 (34.4)	.523	2108 (35.6)	2228 (34.2)	1334 (36.0)	.116	3431 (39.6)	2438 (39.3)	2795 (38.9)	.691
Dialysis	322 (1.0)	341 (1.0)	229 (1.0)	.355	91 (1.5)	88 (1.3)	56 (1.5)	.269	139 (1.6)	78 (1.3)	101 (1.4)	.01
Smoking				<.001				<.001				<.001
Prior smoker	15,758 (47.4)	16,537 (50.0)	10,731 (48.9)		2633 (44.2)	3081 (46.7)	1763 (47.4)		4399 (50.6)	3221 (51.9)	3628 (50.4)	
Current smoker	8350 (25.1)	8441 (25.5)	5367 (24.5)		1675 (28.1)	1891 (28.6)	930 (25.0)		1865 (21.5)	1430 (23.0)	1533 (21.3)	
Prior ipsilateral CEA	504 (1.5)	495 (1.5)	310 (1.4)	.595	992 (16.7)	1127 (17.1)	603 (16.2)	.515	1169 (13.5)	907 (14.6)	1054 (14.7)	.053
Prior ipsilateral CAS	114 (0.3)	68 (0.2)	75 (0.3)	.001	265 (4.5)	272 (4.1)	153 (4.1)	.592	149 (1.7)	102 (1.6)	110 (1.5)	.652
Prior contralateral CEA/CAS	4327 (13.0)	4485 (13.6)	2974 (13.6)	.062	941 (15.8)	980 (14.8)	569 (15.3)	.324	1443 (16.6)	1072 (17.3)	1220 (17.0)	.590
Contralateral occlusion	1599 (5.2)	1623 (5.1)	1043 (5.1)	.826	578 (9.7)	620 (9.4)	317 (8.5)	.139	800 (9.2)	482 (7.8)	597 (8.3)	.01
Preoperative medications												
Aspirin	27,618 (83.1)	28,480 (86.1)	18,320 (83.4)	<.001	5017 (84.2)	5663 (85.7)	3166 (85.0)	.056	7744 (89.1)	5672 (91.3)	6455 (89.7)	<.001
P2Y12 inhibitors	12,991 (39.1)	12,172 (36.8)	7868 (35.8)	<.001	4496 (75.4)	5022 (76.1)	2859 (76.8)	.322	7569 (87.1)	5558 (89.4)	6356 (88.3)	<.001
Statin	28,133 (84.6)	28,613 (86.5)	18,876 (86.0)	<.001	4892 (82.1)	5442 (82.4)	3106 (83.4)	.213	7778 (89.5)	5629 (90.6)	6448 (89.6)	.065
β-Blockers	17,582 (52.9)	18,443 (55.8)	12,091 (55.1)	<.001	3133 (52.6)	3415 (51.7)	1967 (52.9)	.475	4914 (56.6)	3606 (58.1)	4051 (56.3)	.087
Anticoagulation	3948 (11.9)	4129 (12.5)	2629 (12.0)	.041	791 (13.3)	858 (13.0)	445 (12.0)	.155	1292 (14.9)	933 (15.0)	989 (13.8)	.062
ACE inhibitors	17,793 (53.5)	17,551 (53.1)	11,819 (53.9)	.172	2996 (50.3)	3193 (48.4)	1946 (52.3)	.001	4601 (53.0)	3282 (52.8)	3929 (54.7)	.052
ASA class IV-V	7044 (21.2)	7337 (22.2)	5399 (24.6)	<.001	1059 (19.3)	1166 (18.7)	672 (20.1)	<.001	2429 (28.0)	1603 (25.8)	2136 (29.8)	<.001
Anatomic high risk	1261 (3.8)	1428 (4.3)	745 (3.4)	<.001	2451 (41.1)	2536 (38.4)	1531 (41.1)	.002	3618 (41.6)	2863 (46.1)	3371 (46.8)	<.001

ACE, Angiotensin-converting enzyme; *ASA*, American Society of Anesthesiologists; *CABG*, coronary artery bypass grafting; *CEA*, carotid endarterectomy; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention; *TCAR*, transcarotid artery revascularization; *TF-CAS*, transfemoral carotid artery stenting; *TIA*, transient ischemic attack.
Data are presented as number (%).

Supplementary Table II (online only). Regional variability in procedural variables and practice patterns of carotid endarterectomy (*CEA*)

	CEA (N = 88,367)			
Regional case volume	**Low**	**Medium**	**High**	***P* value**
Preoperative stress test	10,070 (30.3)	11,750 (35.6)	5606 (25.6)	<.001
Elective procedures	28,660 (86.1)	29,019 (87.8)	18,620 (84.8)	<.001
General anesthesia	30,596 (92.0)	31,210 (94.5)	20,530 (93.5)	<.001
Protamine	22,825 (68.6)	24,700 (74.8)	17,422 (79.4)	<.001
CEA technique				<.001
Conventional	29,029 (87.3)	28,765 (87.3)	19,851 (90.7)	
Eversion	4229 (12.7)	4190 (12.7)	2043 (9.3)	
Patch use (conventional CEA)	26,999 (93.0)	26,562 (92.5)	19,067 (96.1)	<.001
Patch type				<.001
Prosthetic	28,492 (85.6)	27,705 (84)	19,871 (90.5)	
Autogenous vein	349 (1.1)	720 (2.2)	154 (0.7)	
Intraoperative shunting				<.001
Routine	14,472 (43.5)	12,294 (37.2)	9052 (41.3)	
Selective	3213 (9.7)	2612 (7.9)	1540 (7.0)	
Drain use	12,541 (37.7)	13,955 (42.3)	7228 (32.9)	<.001
EEG monitoring	6797 (20.4)	11,104 (33.7)	7877 (35.9)	<.001
Stump pressure	4612 (13.9)	4828 (14.6)	1077 (4.9)	<.001
Completion imaging				<.001
Doppler	17,020 (51.2)	18,225 (55.2)	14,109 (64.3)	
Duplex	7882 (23.7)	9398 (28.5)	4742 (21.6)	
Angiography	1.548 (4.7)	1139 (3.5)	914 (4.2)	

EEG, Electroencephalogram.
Data are presented as number (%).

Supplementary Table III (online only). Regional variability in procedural variables and practice patterns of TF-CAS and TCAR

	TF-CAS (N = 16,298)				TCAR (N = 22,103)			
	Low	**Medium**	**High**	***P* value**	**Low**	**Medium**	**High**	***P* value**
Preoperative stress test	1078 (18.1)	1309 (19.9)	741 (19.9)	.02	2499 (28.8)	1914 (31.2)	1644 (23.0)	<.001
Elective procedures	4386 (73.6)	4810 (72.8)	2785 (74.8)	.092	7781 (89.6)	5650 (90.9)	6216 (86.3)	<.001
General anesthesia	1447 (24.3)	814 (12.3)	790 (21.3)	<.001	7126 (82.1)	4840 (77.9)	6621 (92.0)	<.001
Protamine	637 (11.8)	950 (16.2)	461 (16.1)	<.001	7537 (87.9)	5266 (86.2)	6027 (85.0)	<.001
Completion angiography	4298 (77.6)	4871 (83.9)	2821 (81.6)	<.001	5463 (63.0)	3675 (59.3)	4805 (67.3)	<.001
Prestent ballooning	3134 (68.7)	3482 (69.0)	1988 (68.6)	.907	7061 (87.0)	5415 (90.5)	5864 (85.6)	<.001
Poststent ballooning	4037 (69.0)	4082 (62.7)	2497 (68.0)	<.001	3163 (36.8)	2417 (39.2)	3446 (48.4)	<.001

TCAR, Transcarotid artery revascularization; *TF-CAS*, transfemoral carotid artery stenting.
Data are presented as number (%).