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Demystifying the outcome disparities in carotid revascularization: Utilization of experienced centers

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ABSTRACT

Background: The present study examined race- and insurance-based disparities in utilization of high-volume centers for carotid revascularization.

Methods: Adults (≥18 years) undergoing carotid endarterectomy or carotid artery stenting were identified in the 2012–2019 National Inpatient Sample. Annual, institutional volume of carotid endarterectomy and carotid artery stenting were tabulated, and hospitals in the highest and lowest quartiles were considered high-volume centers and low-volume centers, respectively. Multivariable logistic models were developed to evaluate the association of race and insurance status with high-volume center utilization. Logistic and linear regression was used to examine the association of high-volume centers with outcomes of interest.

Results: Of an estimated 583,200 eligible patients, 60.3% underwent carotid revascularization at high-volume centers. Treatment at high-volume centers was associated with improved outcomes, including decreased odds of mortality/stroke/myocardial infarction (adjusted odds ratio 0.76, 95% confidence interval: 0.60–0.96) and a decrement in length of stay (β: -0.19, 95% confidence interval: -0.25 to 0.12) and hospitalization costs by $2,000 (95% confidence interval: 1,800–2,300). After adjustment, Black (adjusted odds ratio 0.52, 95% confidence interval: 0.48–0.55), Hispanic (adjusted odds ratio 0.45, 95% confidence interval: 0.42–0.55), and other non-White patients (adjusted odds ratio 0.49, 95% confidence interval: 0.45–0.52) had lower odds of undergoing carotid revascularization at high-volume centers compared to White patients. Similarly, Medicaid (adjusted odds ratio 0.87, 95% confidence interval: 0.80–0.94) and lack of insurance (adjusted odds ratio 0.84, 95% confidence interval: 0.77–0.92) were associated with lower odds of high-volume center utilization relative to private insurance.

Conclusion: Patients of color and those with Medicaid or lack of insurance used high-volume centers at lower rates. Further systemic efforts to ensure equitable access to experienced centers may reduce observed disparities in carotid revascularization.

Introduction

As the fifth most common cause of death in the United States, stroke is a major public health burden and is associated with carotid artery stenosis in 15% of cases (~41,000 annual events).[1,2] Revascularization procedures such as carotid endarterectomy (CEA) and carotid artery stenting (CAS) are definitive and well-studied modalities that are used in the treatment of select patients with significant carotid artery stenosis. With advances in interventional technologies, the relative merits and decision making regarding choice of therapy remains debated in the literature.[3] Regardless of whether CEA or CAS is pursued, mounting evidence suggests the presence of disparities in carotid revascularization amongst non-White and underinsured patients. Not only are such patients less likely to undergo carotid revascularization when

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indicated, they also experience significantly worse postoperative outcomes.[4,5]

Reported nearly 2 decades ago by Birkmeyer et al, higher institutional operative volume has been associated with superior outcomes following a multitude of complex procedures.[6] However, several investigators have demonstrated that non-White and underinsured patients are significantly less likely to receive care at high-volume centers (HVC).[7–9] In a single-state study of 10 complex procedures, CEA was among the operations associated with disparities in utilization of HVC for patients of color and those without private insurance.[10]

With implications toward policy and health care coverage, the present study examined the association of sociodemographic factors with receiving carotid revascularization at HVC at the national level. We further evaluated the association of HVC status with clinical outcomes and resource utilization of CEA and CAS in a contemporary cohort. We hypothesized that non-White and underinsured patients would have reduced HVC utilization and experience worse postoperative outcomes.

Methods

The 2012 to 2019 National Inpatient Sample (NIS) was queried to identify adult ($\geq$18 years) patients who underwent elective carotid revascularization (CEA or CAS). The NIS is the largest, publicly available, all-payer inpatient database in the United States and is maintained by the Agency for Healthcare Research and Quality (AHRQ) as part of the Healthcare Cost and Utilization Project (HCUP).[11] Using trend and discharge weights, the NIS provides accurate estimates for approximately 97% of all hospitalizations in the United States.

We used International Classification of Diseases, Ninth and Tenth Revisions (ICD-9 and ICD-10) procedure codes to identify admissions for CEA (ICD-9: 38.12; ICD-10: 03CH0ZZ, 03CJ0ZZ, 03CK0ZZ, 03CL0ZZ) or CAS (ICD-9: 00.63; ICD-10: 037H3DZ, 037J3DZ, 037K3DZ, 037L3DZ). To enhance homogeneity, we excluded patients receiving percutaneous coronary intervention (PCI), coronary artery bypass (CABG), and endovascular repair of intracranial vessels during the same hospitalization. Symptomatic carotid artery disease was defined using diagnoses for carotid stenosis or occlusion with cerebral infarction, transient ischemic attack, or amaurosis fugax, as previously described elsewhere.[12,13]

The annual institutional case volume for combined CEA and CAS was calculated using unique hospital identifiers within each year, since the NIS does not allow for tracking across years. Centers were grouped into 4 quantiles of volume. For clarity, comparisons are reported between the lowest (low-volume center [LVC], median volume 10) and the highest-volume quartiles (high-volume center [HVC], median volume 150). A similar designation was applied for CEA and CAS separately, with the top volume quartiles defined as high-CEA and high-CAS, respectively.

Patient demographics and hospital characteristics of interest included age, sex, race, insurance payer, teaching status, geographic region, and bed size as defined in the HCUP data dictionary.[11] The modified Elixhauser Comorbidity Index, a previously validated composite score of 30 comorbidities, was used to quantify the burden of chronic conditions.[14] The primary outcome of interest was HVC utilization among non-White and underinsured patients, while secondary outcomes included postprocedural complications, hospital length of stay (LOS), and hospitalization costs. Complications considered were in-hospital mortality, stroke, and myocardial infarction (MI). A composite outcome of postoperative death, stroke, or MI was also assessed. Costs were calculated using cost-to-charge ratios provided by HCUP and inflation-adjusted to the 2019 U.S. Personal Health Care Index.

Categorical variables are reported as frequency (%), and continuous variables are reported as mean with standard deviation (SD) or median and interquartile range (IQR), if non-normally distributed. The Kruskal Wallis and χ^2 tests were used to compare continuous and categorical variables, respectively. Multivariable logistic regression models were developed to assess the association of race and insurance status with receipt of carotid revascularization procedures at HVC. Additionally, logistic and linear regression models were used to evaluate the association of receiving care at HVC with outcomes of interest. The least absolute shrinkage and selection operator (LASSO) was used for variable selection. This automated algorithm reduces model overfitting and improves out-of-sample reliability.[15] We selected models to minimize the mean squared error term and evaluated them using the receiver-operating characteristics curve and Akaike and Bayesian information criteria, as appropriate. All statistical analyses were performed using STATA 16.0 (StataCorp LP, College Station, TX). The study was deemed exempt from full review by the Institutional Review Board at the University of California, Los Angeles.

Results

Of an estimated 800,465 hospitalizations considered for analysis, 583,200 (72.9%) met inclusion criteria. Of these patients, 351,885 (60.3%) underwent carotid revascularization at HVC (82.6% CEA, 17.4% CAS), whereas 26,575 (4.6%) were treated at LVC (92.1% CEA, 7.9% CAS). There was no significant difference in age and sex between patients in the 2 cohorts. Compared to LVC, HVC patients were more commonly White (90.3 vs 81.4%, $P < .001$) and less frequently insured by Medicaid (3.5 vs 5.2%, $P < 0001$; Table I). Patients in the HVC cohort less commonly presented with symptomatic carotid disease (2.0 vs 3.1%, $P < .001$) and more frequently received CAS (17.4 vs 7.9%, $P < .001$).

On unadjusted analysis, HVC hospitalizations exhibited lower rates of postoperative MI (0.5 vs 0.8%, $P = .02$) but not mortality or stroke (Table II). Patients at HVC experienced lower rates of mortality/stroke/MI (1.5 vs 1.8%, $P = .06$), shorter LOS (1.7 $\pm$ 2.3 vs 1.9 $\pm$ 2.2 days, $P < .001$), and lower hospitalization costs ($9,200 [7,000–12,600] vs $10,800 [8,200–14,900], $P < .001$, Table II). After adjustment for patient, operative, and hospital characteristics, treatment at HVC was associated with reduced odds of mortality/stroke/MI (AOR 0.76, 95% CI: 0.60–0.96) and a decrement in LOS (β: −0.19 days, 95% CI: −0.25 to 0.12) and hospitalization costs (β: −$2,000, 95% CI: −2,300 to 1,800) with LVC as reference (Table III). When stratified by operation, high-CEA volume centers remained associated with significantly decreased odds of mortality/stroke/MI following CEA (AOR 0.77, 95% CI: 0.61–0.96, ref: low-CEA). There were no significant differences in adjusted outcomes after CAS based on annual CAS caseload volume (Figure 1). Other factors independently associated with mortality/stroke/MI, LOS, and hospitalization costs are shown in Supplementary Tables S1 through S3.

We subsequently evaluated various sociodemographic factors and their association with HVC utilization. Compared to LVC, a greater distribution of White patients received care in HVC ($P < .001$, Figure 2). Privately insured patients underwent carotid revascularization in higher-volume centers compared to Medicaid patients ($P < .001$). After risk adjustment, Black (AOR 0.52, 95% CI: 0.48–0.55), Hispanic (AOR 0.45, 95% CI: 0.42–0.48), and other non-White patients (AOR 0.49, 95% CI: 0.45–0.52) had lower odds of undergoing carotid revascularization at HVC compared to White patients (Table IV). Relative to their White counterparts, non-White patients experienced a significant stepwise decrease in odds of undergoing carotid revascularization at higher-volume centers (Figure 3, *A*). Furthermore, Medicaid (AOR 0.87, 95% CI: 0.80–0.94)

Table I
Patient, clinical, and hospital characteristics stratified by annual carotid revascularization volume quartile

	Lowest (n = 26,575)	Second (n = 63,550)	Third (n = 141,190)	Highest (n = 351,885)	*P* value
Age, y	71.1 ± 9.0	71.4 ± 9.0	71.3 ± 9.1	71.0 ± 9.0	<.001
Female	40.6	42.5	41.0	40.7	.002
Elixhauser Comorbidity Index	3 (2-4)	2 (1-4)	2 (1-4)	2 (1-4)	<.001
Comorbidities					
Anemia	1.5	1.2	1.1	1.0	.002
Cardiac arrhythmias	1.8	1.9	1.9	1.8	.19
Late-stage renal disease	1.4	1.3	1.4	1.4	.85
Coagulopathies	1.5	1.6	1.4	1.3	.29
Congestive heart failure	9.0	9.2	9.2	9.9	.002
Coronary artery disease	40.9	42.0	43.8	45.7	<.001
Diabetes	35.4	33.4	33.7	33.4	.03
Hypertension	82.6	81.8	82.7	82.5	.30
Liver disease	1.3	0.9	1.0	1.0	.14
Neurologic disorders	3.9	3.8	3.7	3.4	.004
Pulmonary circulation disorders	1.6	1.5	1.4	1.5	.61
Race					
White	81.4	84.3	86.0	90.3	<.001
Black	6.2	5.1	4.3	4.0	<.001
Hispanic	6.6	5.9	5.4	3.2	<.001
Other*	5.8	4.8	4.2	2.6	<.001
Primary payer					
Private	17.2	17.8	18.0	18.5	<.001
Medicare	75.2	74.7	75.4	75.5	.35
Medicaid	5.2	4.7	4.0	3.5	<.001
Other†	2.4	2.8	2.7	2.5	.29
Procedure type					
CEA	92.1	90.4	86.2	82.6	<.001
CAS	7.9	9.6	13.8	17.4	<.001
Symptomatic	3.1	2.3	2.4	2.0	<.001
Hospital region					<.001
Northeast	17.6	20.9	14.7	14.3	
Midwest	29.0	25.8	29.0	24.0	
South	25.0	34.4	35.9	50.7	
West	28.4	18.9	20.4	11.0	
Teaching status					<.001
Urban academic	46.8	45.4	55.4	74.7	
Urban nonacademic	36.8	40.8	36.7	22.0	
Rural	16.5	13.8	8.0	3.4	
Bed size					<.001
Large	29.6	36.6	48.7	68.5	
Medium	37.7	33.5	35.3	22.7	
Small	32.7	29.9	16.0	8.8	

CAS, carotid artery stenting; *CEA*, carotid endarterectomy; *HVC*, high-volume centers; *LVC*, low-volume centers.
* Indicates a combined group of Asian, Pacific Islander, Native American, and other races as defined by NIS.
† Indicates a combined insurance status including self-pay, uninsured, and other. Age reported as mean with standard deviation, Elixhauser Comorbidity Index as median with interquartile range, and the remainder of characteristics as percentage.

Table II
Unadjusted outcomes after carotid revascularization stratified by volume quartile

	Lowest	Second	Third	Highest	*P* value
Mortality	0.3	0.3	0.3	0.3	.92
Postoperative stroke	0.9	1.0	0.9	0.9	.32
Myocardial infarction	0.8	0.6	0.5	0.5	.02
Mortality/stroke/MI	1.8	1.8	1.6	1.5	.06
LOS, d	1.9 ± 2.2	1.8 ± 2.4	1.8 ± 2.2	1.7 ± 2.3	<.001
Hospitalization costs ($1,000)	10.8 (8.2–14.9)	10.6 (8.0–14.2)	10.2 (7.8–13.7)	9.2 (7.0–12.6)	<.001

Outcomes reported as percentage for dichotomous outcomes and mean with standard deviation or median with IQR for continuous outcomes.
CI, confidence interval; *LOS*, length of stay; *MI*, myocardial infarction.

and uninsured patients (AOR 0.84, 95% CI: 0.77–0.92) had decreased odds of being treated at HVC, relative to privately insured patients (Table IV). The adjusted odds of undergoing carotid revascularization in different center volume quartiles stratified by insurance status are shown in Figure 3, *B*.

To assess whether the association between sociodemographic factors and receiving care at HVC was independent of operation type, we performed a sensitivity analysis examining the odds of undergoing carotid revascularization at high-volume centers for each revascularization technique (CEA or CAS). Compared to their White counterparts, non-White patients had lower odds of receiving CEA (AOR 0.60, 95% CI: 0.55–0.65) and CAS (AOR 0.81, 95% CI: 0.71–0.92) at both high-CEA and high-CAS volume hospitals, respectively. Compared to the privately insured, Medicaid (AOR 0.76, 95% C: 0.70–0.83) and uninsured patients (AOR 0.83, 95% CI: 0.73–0.94) had lower odds of receiving care at high-CEA

Table III
Adjusted outcomes associated with highest quartile of annual carotid revascularization caseload with lowest quartile as reference

	AOR or β coefficient	95% CI	*P* value
Mortality	0.68	0.34–1.21	.19
Postoperative stroke	0.89	0.65–1.23	.49
Myocardial infarction	0.60	0.41–0.88	.008
Mortality/stroke/MI	0.76	0.60–0.96	.02
LOS, days	-0.19	-0.24 to 0.13	<.001
Hospitalization costs ($1,000)	-2.0	-2.1 to 1.8	<.001

Outcomes reported as adjusted odds ratio for dichotomous outcomes and β-coefficient for continuous outcomes with corresponding 95% confidence intervals for both. Models included patient demographics (age, sex, race, primary payer), comorbidities (anemia, cardiac arrhythmias, congestive heart failure, coronary artery disease, diabetes, neurologic disorders), clinical characteristics (procedure type, operative year, symptomatic carotid disease), and hospital characteristics (region, teaching status, bed size).
AOR, adjusted odds ratio; *CI*, confidence interval; *MI*, myocardial infarction.

volume hospitals. There were no significant differences in odds of receiving CAS at high-CAS volume hospitals based on insurance coverage.

Discussion

Given the significant public health burden of stroke, examining access to high-quality definitive treatment is fundamental to reducing complications and expenditures. While prior work has exhibited inferior outcomes for non-White and underinsured

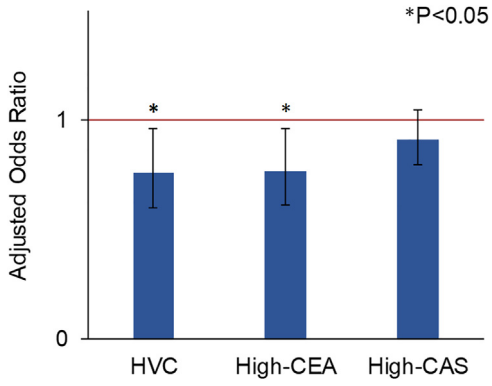

Figure 1. Adjusted odds of mortality/stroke/myocardial infarction by operation group at high-volume centers with low-volume centers as reference. High-CEA and high-CAS indicate top quartile for annual hospital caseload of CEA and CAS, respectively. *CAS*, carotid artery stenting; *CEA*, carotid endarterectomy.

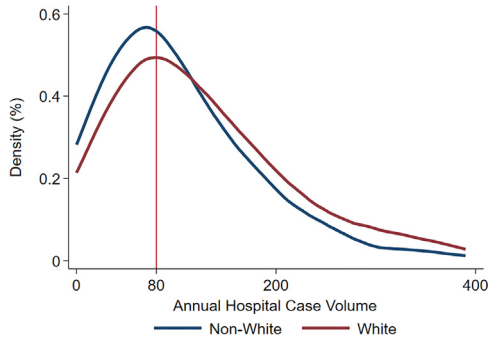

Figure 2. Kernel distribution density of annual hospital carotid revascularization case volume stratified by race. Vertical line indicates the cutoff for high-volume centers.

Table IV
Factors independently associated with high volume center utilization for carotid revascularization (model C-statistic: 0.87)

	AOR	95% CI	*P* value
Age (per year)	1.00	1.00–1.00	.68
Female	0.99	0.97–1.02	.70
Comorbidities			
Anemia	0.87	0.76–0.99	.04
Cardiac arrhythmias	0.94	0.91–0.98	.002
Congestive heart failure	1.03	0.98–1.08	.27
Coronary artery disease	1.09	1.06–1.12	<.001
Diabetes	1.00	0.97–1.03	.86
Neurological disorders	0.87	0.81–0.94	<.001
Race			
White	Reference		
Black	0.52	0.48–0.55	<.001
Hispanic	0.454	0.42–0.48	<.001
Other*	0.49	0.45–0.52	<.001
Insurance coverage			
Private	Reference		
Medicare	1.04	1.00–1.09	.10
Medicaid	0.87	0.80–0.94	<.001
Other†	0.84	0.77–0.92	<.001
Type of procedure			
CEA	Reference		
CAS	1.39	1.34–1.45	<.001
Symptomatic	0.73	0.66–0.81	<.001
Hospital region			
Northeast	Reference		
Midwest	1.04	0.90–1.20	.57
South	2.62	2.30–2.98	<.001
West	0.64	0.54–0.76	<.001
Teaching status			
Urban, academic	Reference		
Urban, nonacademic	0.23	0.20–0.27	<.001
Rural	0.08	0.06–0.10	<.001
Bed size			
Large	Reference		
Medium	0.23	0.20–0.25	<.001
Small	0.13	0.11–0.16	<.001
Year	0.95	0.93–0.97	<.001

AOR, adjusted odds ratio; *CI*, confidence interval; *CAS*, carotid artery stenting; *CEA*, carotid endarterectomy.
* A combined group of Asian, Pacific Islander, Native American, and other races as defined by NIS.
† A combined insurance status including self-pay, uninsured, and other.

patients after carotid revascularization,[1,4,16] national data regarding utilization of experienced centers are currently lacking. In the present study, we found that Black, Hispanic, and other non-White patients had lower odds of receiving treatment at HVC relative to White individuals. Similarly, patients with Medicaid or no insurance had lower rates of HVC utilization for carotid revascularization compared to those who were privately insured. High-volume centers were characterized by lower rates of major adverse events, shorter hospitalization duration, and lower costs.

Owing to the robust literature demonstrating the hospital volume–outcome relationship in various complex surgical procedures,[6,17–20] many organizations have accepted institutional caseload as an indicator of quality. Initiatives such as the Leapfrog "Volume Pledge" have proposed to limit complex surgical procedures to hospitals that meet minimum volume requirements.[21] Several studies have demonstrated improved outcomes in high-volume hospitals following carotid revascularization.[22,23] In a systematic review, Poorthuis et al reported high operator and hospital volumes to be associated with a decreased risk of procedural death and stroke following CEA and CAS.[24] Pooling across 49 studies with more than 4 million patients, they found an adjusted odds ratio of 0.62 for death or stroke in high-volume hospitals. In the present study, a cutoff of 80 annual carotid revascularization procedures was used to define HVC, with a median of 150 cases performed in

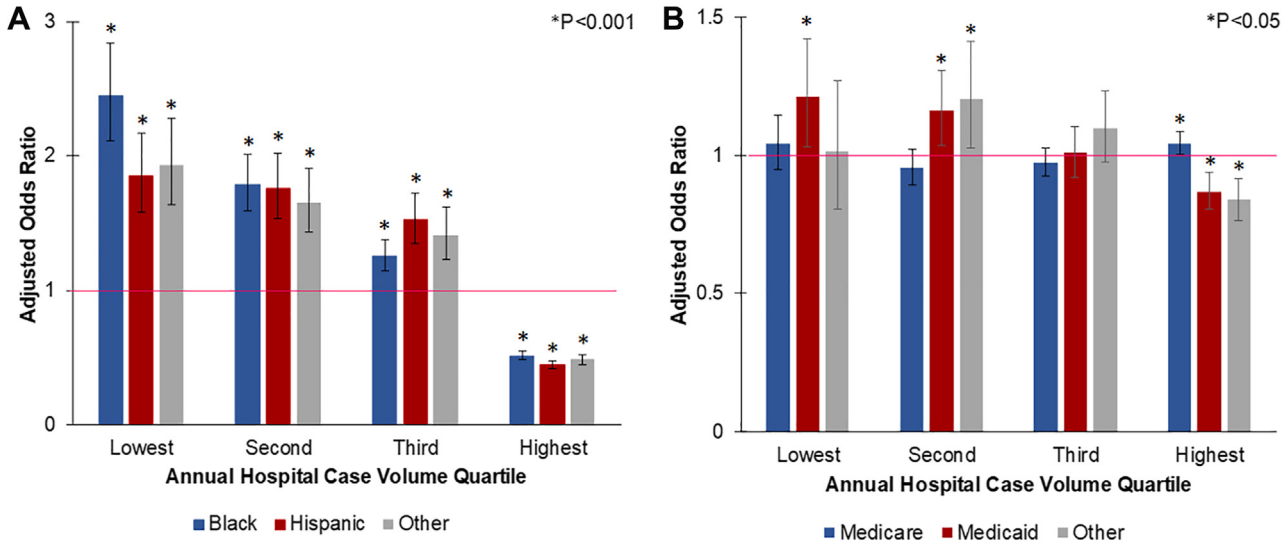

Figure 3. Adjusted odds of undergoing carotid revascularization in hospitals at different case volume quartiles by race with White as reference (A) and primary payer with private insurance as reference (B).

these institutions. Notably, we found low overall rates of mortality, stroke, and MI, signaling an improvement in operative technique and management following these procedures. However, a statistically significant difference in the composite endpoint of death/stroke/MI between HVC and LVC demonstrate persistent inter-hospital variation. Furthermore, decreased resource use in HVC corroborate superior outcomes in experienced centers, supporting the continued utility of procedural caseload as an indicator of hospital quality in carotid revascularization.

Improving racial and socioeconomic disparities in cardiovascular health requires recognition of potentially modifiable factors. Notably, our study found significant existing disparities in the distribution of patients at high- and low-volume centers based on race. Compared to their White counterparts, patients of color had lower rates of undergoing carotid revascularization at HVC. This observation may be, in part, attributable to complex factors that include physician referral patterns and institutional barriers. A previous study showed that primary care physicians face greater difficulties in obtaining access for Black patients to high-quality physicians and hospitals.[25] In a systematic review of 150 studies, Geiger found strong evidence for provider and institutional bias as a significant contributor to racial disparities in American health care.[26] Furthermore, there is a growing emphasis on the impact of structural racism on health, with a large body of literature implicating segregation and other systemic factors in diminished health access for patients of color.[27–30] Hayanga et al showed that in the most segregated counties, an increase in Black and Hispanic populations was associated with decreased availability and use of high-quality surgical services, even after adjusting for socioeconomic and health characteristics.[31] Given the complex and multifactorial mediators of health disparities, our findings provide additional considerations when developing efforts to mitigate inequities in patients with carotid artery stenosis. While increasing access to experienced centers may serve as an avenue for improving outcomes, further work is necessary to elucidate and evaluate additional interventions that address health disparities experienced by non-White patients.

In addition to race, we found uninsured status and Medicaid coverage to be associated with lower odds of receiving treatment at HVC. This finding is consistent with a previous study from California, which reported lower utilization of high-volume hospitals for various complex operations in this population.[10] Studies examining referral patterns in other surgical specialties have similarly found that patients with Medicaid coverage or lack of insurance are less likely to be offered or referred to surgical care.[32,33] While the Leapfrog Group aims to improve care for insured individuals,[21] selective referral for those with private insurance may not resolve the underlying issue of access for underinsured patients. Further systemic efforts are necessary to prevent the maintenance and exacerbation of existing insurance disparities among patients with carotid artery stenosis.

The present study has several limitations including those inherent to its retrospective nature. Due to the administrative nature of NIS, diagnoses and procedures are identified through ICD codes, which are influenced by provider and hospital practices. The high proportion of asymptomatic patients in our study may reflect potential inaccuracy in diagnoses codes or inability to document timing of symptoms. Given that symptomatic patients generally have higher rates of complications, discrepancies in symptom documentation may impact our findings. Nonetheless, we used specific codes for carotid stenosis with or without symptoms to stratify the study population. Clinical-level data, such as imaging studies or administration of or adherence to postoperative antiplatelet therapy, could not be captured in the NIS. Furthermore, we were only able to capture transfemoral stent procedures and thus have no data on sociodemographic disparities in transcarotid stent operations. Despite these limitations, we used the largest available all-payer database and robust statistical methods to reduce the risk of bias.

In conclusion, high-volume centers remain associated with decreased risk of complications and resource use after carotid revascularization. Patients of color and those with Medicaid coverage or lack of insurance use experienced centers at lower rates. Further systemic efforts to ensure equitable utilization of experienced centers may reduce observed disparities in carotid revascularization.

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Conflict of interest/Disclosures

The authors have no related conflicts of interest to declare.

Supplementary materials

Supplementary material associated with this article can be found in the online version https://doi.org/10.1016/j.surg.2022.03.043.

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