A carotid web (CW) is a linear, shelf-like luminal irregularity arising from the posterior wall of the proximal internal carotid artery. This entity is recognized as a source of recurrent stroke in young patients without conventional vascular risk factors. There has been no previous studies demonstrating that specific web morphological characteristics correlate with a higher stroke risk. The authors aim to report distinct morphological features of symptomatic and asymptomatic CWs.

Methods
Population
We performed a single-institution cross-sectional study of patients with CWs detected on CT angiography (CTA) of the neck. Patients were identified through a radiology report search application via the electronic medical record. This application allows input of various parameters for patient demographics, date of study, and specific keywords.

Results
A total of 86 CWs were identified, 14 of which presented with stroke (16.3%). Patients presenting with stroke had webs that were significantly longer (4.18 mm vs 2.20 mm, p = 0.001) and were situated at more acute angles relative to the carotid wall (73.2° vs 94.9°, p = 0.004). Additionally, patients presenting with stroke had higher WBRs compared to the asymptomatic cohort (0.50 vs 0.36, p = 0.008). The optimal threshold associated with stroke was web length ≥3.1 mm (OR 15.2, 95% CI 3.73–61.8; p < 0.001), web angle ≤90.1° (OR 5.00, 95% CI 1.42–17.6; p = 0.012), and WBR ≥0.50 (OR 30.0, 95% CI 5.94–151; p < 0.001).

Conclusions
Patients with CWs that occupy more than half of the diameter of the carotid bulb lumen and are situated at acute angles relative to the carotid wall are more likely to present with acute ischemic stroke. Additional studies are needed to determine the long-term outcomes of these lesions.

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Keywords
carotid web; stroke; vascular disorders

Abbreviations
CEA = carotid endarterectomy; CTA = CT angiography; CW = carotid web; ROC = receiver operating characteristic; WBR = web-to-bulb ratio.


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Patients who were identified with the keywords “carotid” and “web” or “shelf” or “diaphragm” mentioned consecutively within the interpreting radiologist’s report were included in the study. Prior to the conception of this study, all CTA studies were interpreted by one of four attending neuroradiologists.

All data (including patient demographic information, baseline comorbidities, and clinical characteristics) were recorded retrospectively via the electronic medical record. Patients were categorized based on whether they presented with an acute ischemic stroke of undetermined etiology ipsilateral to their web, or if the stroke was presumed to be caused by the CW. Cases were selected based on a negative stroke workup by Trial of ORG 10172 in Acute Stroke Treatment (TOAST) criteria (patients with > 1 possible stroke etiology were excluded). All patients presenting with stroke underwent a protocolized workup including noncontrasted CT of the head, CTA of the head and neck, MRI of the brain, transthoracic and/or transesophageal echocardiogram, laboratory workup, and inpatient telemetry. Asymptomatic controls were selected among patients admitted following blunt trauma to the head and neck, with no history of stroke. At our institution, all patients presenting to the trauma center undergo a CTA of the neck to evaluate for blunt cervicovascular injury.

We included patients who presented between January 1, 2016, and January 31, 2021. This time interval was chosen because it incorporated a period in which CTA of the neck was routinely implemented in the workup of patients with trauma, thus bolstering the sample size of our asymptomatic cohort. Institutional review board approval was obtained.

CW Morphology

A CW was radiographically defined on CTA as a thin intraluminal filling defect along the posterior wall of the carotid bulb, best seen on the sagittal plane, with a septum evident on the axial plane. All CTAs (thin-cut axial, coronal, and sagittal maximum intensity projections) with the mention of CW in the radiology report were systematically reviewed by a neurointerventionalist, neurocritical care intensivist, and neurosurgery resident physicians. The following CW morphological variables were recorded based on CTA: length (millimeters), thickness (millimeters), and angle (degrees) between the main axis of the web and the adjacent carotid wall (Fig. 1A–C). The proportion of carotid bulb occupied by the web was calculated as a ratio (web-to-bulb ratio [WBR], Fig. 1D). All measurements were performed on the imaging slice in which the CW appeared to be longest within the lumen of the carotid bulb on the sagittal plane. We additionally noted the presence or absence of extracranial carotid fibromuscular dysplasia or calcified atherosclerosis. To avoid misclassification, lesions with associated calcification or characteristics of carotid dissection (occlusion or extension distal to the carotid bulb) were excluded from the study.

Imaging Technique

CTA neck examinations (Philips Brilliance) were performed using a standard protocol. Examinations were performed in helical scanning mode, with coverage spanning the aortic arch to the sella turcica. Projection reconstructions (3-mm slice thickness) were reconstructed in the coronal and sagittal planes.

Statistical Analysis

The rate of CWs identified per 1000 scans was calculated for each year, and a linear regression model was used to evaluate for a significant trend in the rate of CW identification over time. Patients with an identified CW were then separated into two groups based on whether they had an acute ischemic stroke ipsilateral to their web. Demographics and medical comorbidities were compared between the groups. Student t-test and chi-square test were used for continuous and categorical characteristics, respectively. Web morphology, including length, thickness, angle, and WBR, were compared between the two groups using the Student t-test. A significance level of 0.05 was used for all analyses.
A receiver operating characteristic (ROC) curve was then constructed for the association of each morphological parameter (length, angle, and WBR) with presentation with ipsilateral stroke. These parameters were then dichotomized using optimal cutoffs determined by maximizing the respective Youden index. Univariate odds ratios were calculated along with 95% confidence intervals.

Results

CW Detection

A total of 152 CTA studies mentioned CW in the interpretation report (158 CWs total, 6 patients with bilateral webs). The distribution of webs identified per year is shown in Table 1. There was a significant increase in the number of CWs identified over time, based on the linear model (p = 0.036). This is demonstrated graphically in Fig. 2.

Clinical Characteristics

Of the 158 initially identified CWs, 44 (27.8%) originated distal to the carotid bulb and 28 (17.7%) had adjacent calcification and were subsequently excluded from statistical analysis. Of the remaining 86 CWs, 14 had associated anterior circulation ipsilateral ischemic strokes (16.3%). All stroke patients presented with large-vessel occlusion (internal carotid artery or M1 segment of the middle cerebral artery). Demographic and comorbidity characteristics are presented in Table 2. The patients with strokes had significantly higher rates of hypertension and hyperlipidemia than those who did not have strokes, but these groups were otherwise similar. Among the patients...
presenting with stroke, 4 (28.6%) underwent carotid endarterectomy (CEA), 5 (35.7%) underwent carotid artery stenting, and 5 (35.7%) were treated with aspirin alone.

**Morphology of Symptomatic and Asymptomatic CWs**

Morphological characteristics of the CWs, including length, thickness, angle, and WBR, are presented in Table 3. The patients presenting with strokes had CWs that were significantly longer (4.18 mm vs 2.20 mm, p = 0.001) and were situated at more acute angles relative to the carotid wall (73.2° vs 94.9°, p = 0.004). Additionally, patients presenting with stroke had higher WBRs compared to the asymptomatic cohort (0.50 vs 0.36, p = 0.008). Web thickness was not significantly different between patients who had strokes and those who did not (1.85 mm vs 1.72 mm, p = 0.609).

ROC curves for web length, angle, and WBR are shown in Fig. 3. For web length, the optimal threshold for association with stroke was ≥ 3.1 mm. In this sample, the sensitivity and specificity at this threshold was 78.6% and 80.6%, respectively, with an odds ratio (OR) of 15.2 (95% CI 3.73–61.8; p < 0.001). This length threshold gave positive and negative predictive values of 44.0% and 95.1%, respectively. The optimal threshold for web angle was ≤ 90.1°, with a sensitivity and specificity of 71.4% and 66.7%, respectively, and OR 5.00 (95% CI 1.42–17.6, p = 0.012). This angle threshold gave positive and negative predictive values of 50.0% and 96.8%, respectively. For WBR, the optimal threshold was ≥ 0.50, with sensitivity 85.7% and specificity 83.3%, and OR 30.0 (95% CI 5.94–151, p < 0.001). This WBR threshold gave positive and negative predictive values of 29.4% and 92.3%, respectively.

**Discussion**

In this cross-sectional study, we have incorporated our data on stroke and trauma patients to determine the morphological features of asymptomatic and symptomatic CWs. This is the first study reporting an association between morphological characteristics of CWs and stroke presentation. Specifically, patients with longer webs occupying a higher proportion of the carotid bulb lumen were more likely to have presented with an acute ischemic stroke.

Our data confirm a trend toward increased incidence of CW detection on CTA over time, similar to other comprehen-
hensive stroke centers. This is probably attributable to the increased attention CWs have received in clinical research. CTA is the diagnostic study of choice because it is high resolution, can identify calcium, and is not strictly a lumen-based study. Additionally, detection of CW on CTA has been shown to have high interrater agreement. All the images in our study were interpreted by a consistent group of neuroradiologists at a single institution, reducing the risk of differential misclassification bias.

The reported prevalence of CW among patients with cryptogenic stroke ranges widely, from 9.4% to 37%. Contrary to prior studies demonstrating a preponderance among patients of African descent, our data did not suggest a significant association between CW and ethnicity. Differences in methodology and population characteristics may explain the discrepancy with prior reports.

The pathophysiological mechanism of stroke due to CW is theorized to be secondary to stagnation of blood flow within the cul-de-sac formed by the CW and subsequent artery-to-artery thromboembolism. The left atrial appendage in the context of atrial fibrillation is a homolog to this phenomenon and is often treated with oral anticoagulation agents. Several studies have found that various morphological subtypes and larger left atrial appendage volume are associated with increased cardioembolic stroke risk in patients with atrial fibrillation. Similarly, higher volumes of flow stasis within a CW theoretically portend a higher stroke risk based on similar mechanisms. Although no volumetric analysis was performed in this study, the ability to stratify stroke risk based on CTA findings may be beneficial given that they are significantly easier to obtain and interpret at most institutions.

Prior studies have speculated that web morphology may impact blood flow patterns leading to thrombus formation. In one study of patients with bilateral CW presenting with stroke, web length ipsilateral to the stroke was found to be longer compared to the asymptomatic side. Another study found that CWs are associated with increased recirculation zones and regional increased wall shear stress metrics that are associated with disturbed flow and thrombogenicity. Furthermore, multiple studies have found no association between degree of stenosis caused by the CW and stroke risk. However, the hemodynamic profiles and methods of determining degree of stenosis between carotid atherosclerosis and CW may not be comparable due to the differences in 3D morphology. Our data suggest that a CW that occupies more than half the diameter of the carotid bulb lumen may be a more suitable predictor of stroke risk.

There are no randomized data to guide treatment for CW. A systematic literature review suggests a high stroke recurrence rate in medically managed symptomatic CW patients, whereas carotid revascularization effectively prevented recurrence of stroke. There is an even greater paucity of evidence surrounding the optimal strategy to prevent stroke in patients with asymptomatic CW. Based on prospective studies, asymptomatic CWs appear to be benign lesions, with no reports of incidentally found webs later presenting with stroke. Based on recent evidence, we have adjusted our practice to treat all patients who present with acute ischemic stroke secondary to CW with CEA or carotid artery stenting. Future studies should be aimed toward long-term follow-up in patients with asymptomatic CWs to better understand the natural history and to guide management in stroke risk prevention.

Our study has limitations, namely the recruitment of patients from a single institution and its retrospective design. It can be difficult to distinguish a CW from small free-floating thrombus, given that their morphological characteristics are similar based on CTA alone. Among the patients who underwent CEA in our cohort, the presence of a CW was confirmed as a thin fibrous projection within the carotid bulb lumen. Specimens sent for pathological analysis in two patients who underwent CEA demonstrated spindle cell proliferation with myxoid degeneration. Larger multicenter studies are necessary to confirm our findings and to determine whether CW morphology is a predictor of stroke risk. Additionally, the stroke-related past medical history and vascular comorbidities were probably significantly underreported in trauma patients when compared to stroke patients, which may account for the discrepancy in underlying stroke risk factors between the two groups. However, our methodology is similar to a previously published report including trauma patients as members of the asymptomatic cohort.

Conclusions

Patients with CWs that occupy more than half of the diameter of the carotid bulb and are situated at acute angles relative to the carotid wall are more likely to present with acute ischemic stroke. Additional studies are needed to determine the natural history of these lesions.

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**Disclosures**

Dr. Jones is a consultant for Cerenovus and MIVI.

**Author Contributions**

Conception and design: Tabibian. Acquisition of data: Tabibian, Salehani, Mahavadi, Rahm, Kaur, Howell. Analysis and interpretation of data: Tabibian, Parr. Drafting the article: Tabibian, Parr. Critically revising the article: Tabibian, Parr, Salehani, Kaur, Jones, Liptrap, Harrigan. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Tabibian. Statistical analysis: Parr. Administrative/technical/material support: Tabibian. Study supervision: Jones, Liptrap, Harrigan.

**Correspondence**

Borna Ethan Tabibian: University of Alabama at Birmingham, AL. betabibian@uabmc.edu.