JHWCR JOURNAL OF HEALTH, WELLNESS AND COMMUNITY RESEARCH 3007-0570

Vol. 3 Issue 7, 2025
Open Access | DOI: 10.61919/c0k47943

Original Article

Diagnostic Accuracy of Carotid Doppler Ultrasonography in Detecting Carotid Artery Stenosis Keeping CT Angiography as Gold Standard in Patients with Cerebral Ischemic Events

Dr. Mahnoor Nasir[1], Dr. Naila Nasir Usmani[1], Dr. Maryam Amjad[1], Dr. Muhammad Waseem Awan[1], Dr. Mahjabeen Mehmood Kamal[1], Dr. Sania Sajjad[1], Dr. Amna Bibi[1]

[1] Department of Radiology, KRL Hospital, Islamabad, Pakistan

Correspondence: Dr. Mahnoor Nasir, dr.mahnoorn7@gmail.com

Received: 01 May 2025	Revised: 08 May 2025	Accepted: 09 June 2025	Published: 30 June 2025

HOW TO CITE

Dr. Mahnoor Nasir et al. 2025. Diagnostic Accuracy of Carotid Doppler Ultrasonography in Detecting Carotid Artery Stenosis Keeping CT Angiography as Gold Standard in Patients with Cerebral Ischemic Events. Journal of Health, Wellness and Community Research. 3, 7 (Jun. 2025), 1–7. DOI:https://doi.org/10.61919/c0k47943

ARTICLE INFORMATION

Author Contributions	Concept: MN, NNU; Design: MN, MA, MWA; Data Collection: MA, MMK, SS, AB; Analysis: MN, MWA; Drafting: MN, NNU, MA, MMK, SS, AB.
Ethical Approval	The study was approved by research ethical board of KRL Hospital, Islamabad, Pakistan
Informed Consent	Written informed consent was obtained from all participants
Conflict of Interest	The authors declare no conflict of interest.
Funding	No external funding.
Data Availability	Available from the corresponding author on reasonable request.
AI Declaration	No generative AI was used for conceptualization, analysis, or content generation. AI use was limited to language refinement, and the authors remain fully responsible for the accuracy, originality, validity, and integrity of the manuscript's content.

ABSTRACT

Background: Carotid artery stenosis is an important contributor to cerebral ischemic events, and accurate vascular imaging is required for appropriate clinical assessment. Carotid Doppler ultrasonography (CDUS) offers a noninvasive and accessible alternative to CT angiography (CTA). Objective: To determine the diagnostic accuracy of CDUS for detecting carotid artery stenosis in patients with cerebral ischemic events, using CTA as the reference standard. Methods: This cross-sectional diagnostic-accuracy study included 120 patients aged 18–75 years presenting to the Department of Radiology, KRL Hospital, Islamabad, from 1 January to 5 April 2025. All participants underwent CDUS and CTA. Diagnostic performance was evaluated using a 2 × 2 contingency table with calculation of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), overall accuracy, and intramodality agreement. Results: CTA identified stenosis in 64 (53.3%) patients, while CDUS was positive in 68 (56.7%). CDUS yielded 60 true-positive, 48 true-negative, 8 false-positive, and 4 false-negative findings. Sensitivity was 93.8% (95% CI, 85.0–97.5), specificity 85.7% (74.3–92.6), PPV 88.2% (78.5–93.9), NPV 92.3% (81.8–97.0), and overall accuracy 90.0% (83.3–94.2). Cohen's κ was 0.80, indicating substantial agreement. Conclusion: CDUS demonstrated high sensitivity, good specificity, and substantial agreement with CTA, supporting its use as a noninvasive initial modality for evaluating carotid artery stenosis in patients with cerebral ischemic events. Keywords: Carotid artery stenosis; carotid Doppler ultrasonography; CT angiography; cerebral ischemic events; diagnostic accuracy.

INTRODUCTION

Stroke and transient ischemic attack (TIA) remain major causes of mortality, long-term neurological disability, and recurrent cerebrovascular morbidity worldwide. A substantial proportion of ischemic cerebrovascular events are associated with atherosclerotic disease of the extracranial carotid arteries, making timely identification of clinically important carotid artery stenosis an essential component of secondary stroke prevention (1). Accurate determination of the presence and severity of carotid stenosis has direct implications for risk stratification and therapeutic decision-making, including optimization of medical therapy and selection of appropriately evaluated patients for carotid endarterectomy or carotid artery stenting (2). Contemporary stroke-prevention guidelines therefore emphasize early vascular assessment in patients presenting with ischemic stroke or TIA, particularly when large-artery atherosclerotic disease is suspected (3).

The clinical importance of carotid imaging is closely related to the degree of arterial narrowing and the patient's symptomatic status. Management decisions may differ substantially between mild, moderate, and severe carotid stenosis, and accurate classification is particularly important when considering revascularization in symptomatic patients (4). Several imaging modalities are available for evaluating extracranial carotid disease, including duplex or carotid Doppler ultrasonography, computed tomographic angiography (CTA), magnetic resonance angiography, and catheter-based digital subtraction angiography. Among these, carotid Doppler ultrasonography (CDUS) is widely used as an initial investigation because it is noninvasive, comparatively inexpensive, widely accessible, repeatable, and capable of providing both structural and hemodynamic information. Nevertheless, its diagnostic performance depends on standardized acquisition and interpretation, particularly when differentiating clinically relevant categories of stenosis (5).

CTA provides high-resolution visualization of the arterial lumen, plaque-related narrowing, occlusion, and vascular anatomy and is commonly used as a confirmatory noninvasive reference examination in symptomatic carotid disease. Its rapid acquisition and detailed multiplanar and three-dimensional reconstruction make it particularly useful in patients undergoing acute or subacute cerebrovascular assessment. However, CTA requires ionizing radiation and iodinated contrast administration and may therefore be unsuitable or less desirable in some patients, including those with significant renal impairment or contrast hypersensitivity. Evidence comparing carotid ultrasonography with CTA and other vascular imaging techniques has shown generally good diagnostic performance, particularly for clinically significant stenosis, while also demonstrating that accuracy may vary according to stenosis threshold, imaging protocol, plaque characteristics, and technical factors (6).

Previous diagnostic-accuracy studies have reported high sensitivity and specificity for duplex ultrasonography when CTA is used as the reference test. Recent comparative evidence has shown substantial agreement between duplex ultrasonography and CTA for the identification of significant carotid atherosclerotic stenosis, although discrepancies may occur in individual patients and across different stenosis categories (7). Evidence from Pakistan has similarly demonstrated favorable diagnostic performance. In a study conducted at the Armed Forces Institute of Radiology and Imaging involving 85 patients and 170 carotid arteries, duplex ultrasonography demonstrated a sensitivity of 92.0%, specificity of 89.0%, positive predictive value of 89.8%, negative predictive value of 92.5%, and overall diagnostic accuracy of 91.1% compared with CTA (8). These findings support the potential usefulness of CDUS as a first-line assessment modality, particularly in settings where immediate access to CTA may be limited.

Despite this generally favorable performance, carotid Doppler assessment is influenced by several patient-related and technical factors. Doppler-derived estimates of stenosis depend substantially on blood-flow velocity measurements, appropriate insonation angle, arterial anatomy, and the hemodynamic consequences of luminal narrowing. Plaque morphology may also affect velocity-based interpretation and agreement between ultrasound and angiographic measurements (9). Studies examining peak systolic velocity and angiographic stenosis grading further demonstrate that the relationship between Doppler parameters and anatomical narrowing is strong but not uniform across all degrees of carotid stenosis (10). Consequently, diagnostic performance established in one population or imaging environment cannot necessarily be assumed to apply unchanged to another, particularly where operator expertise, equipment, vascular-risk profiles, and disease severity differ.

Patients presenting with recent cerebral ischemic events represent a clinically important population in whom rapid, accurate, and accessible assessment of carotid artery disease may influence subsequent investigation and management. However, locally relevant evidence regarding the diagnostic performance of CDUS against CTA in such symptomatic patients remains limited, particularly with respect to variation in performance across patient characteristics and different degrees of stenosis. Establishing the reliability of CDUS in this setting may help clarify its role as an initial diagnostic modality while identifying circumstances in which confirmatory CTA remains necessary.

Therefore, this cross-sectional diagnostic-accuracy study aimed to determine the diagnostic accuracy of carotid Doppler ultrasonography for detecting carotid artery stenosis in patients with cerebral ischemic events, using CT angiography as the reference standard. The primary objective was to determine the sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy of CDUS compared with CTA. Secondary analyses were intended to examine whether diagnostic performance varied according to selected patient characteristics and the severity of carotid stenosis.

MATERIALS AND METHODS

This cross-sectional diagnostic-accuracy study was conducted in the Department of Radiology, KRL Hospital, Islamabad, Pakistan, from 1 January 2025 to 5 April 2025. The study was designed to evaluate the diagnostic performance of carotid Doppler ultrasonography (CDUS) for detecting carotid artery stenosis in patients with recent cerebral ischemic events, using computed tomographic angiography (CTA) as the reference standard. The target population comprised adult patients presenting with ischemic stroke or transient ischemic attack (TIA) who were clinically suitable to undergo both CDUS and CTA during the study period.

Patients aged 18–75 years with a history of ischemic stroke or TIA within the preceding six months were eligible for inclusion. Neurological status was assessed clinically, with the National Institutes of Health Stroke Scale used as part of the evaluation of neurological deficit. Patients were required to be medically suitable for completion of both carotid Doppler ultrasonography and contrast-enhanced CTA to allow direct comparison of the index and reference tests. Patients were excluded if they had previously undergone carotid endarterectomy or carotid artery stenting, had a known allergy to iodinated contrast material, had severe renal impairment, or had another medical condition that contraindicated contrast-enhanced CT imaging.

Participants were enrolled using a non-probability consecutive sampling technique. Eligible patients presenting through the relevant outpatient or emergency services during the study period were considered for recruitment until the required sample size was achieved. A total sample of 120 patients was calculated using previously reported diagnostic-performance estimates for Doppler ultrasonography, including an anticipated sensitivity of 92% and specificity of 89%, with an expected prevalence of carotid stenosis of 50.5%, a 95% confidence level, and an absolute precision of 8%. Written informed consent was obtained from each participant before enrollment and imaging. Participants were informed about the study procedures, voluntary nature of participation, potential benefits, and risks associated with iodinated contrast administration, including nausea, hypersensitivity reactions, and renal complications.

All enrolled participants underwent carotid Doppler ultrasonography followed by assessment with CTA. CDUS was performed using a GE VOLUSON P9 ultrasound system equipped with curvilinear 2.5–5 MHz and linear 5–7 MHz transducers. B-mode imaging and pulsed-wave Doppler assessment were used to evaluate the carotid arteries for luminal narrowing, atherosclerotic plaque, thrombosis, and associated hemodynamic changes. Doppler measurements were obtained with the insonation angle maintained below 60°, with optimization of pulse-repetition frequency and waveform acquisition to improve velocity assessment. Doppler-derived flow characteristics were interpreted together with grayscale morphological findings because velocity measurements and plaque characteristics may influence ultrasonographic classification of carotid stenosis (9,10).

Carotid plaques identified on ultrasonography were categorized as soft, calcified, or mixed according to their sonographic appearance. The severity of carotid stenosis was classified as mild (<50%), moderate (50–69%), severe (70–99%), or complete occlusion (100%). These categories were subsequently compared with the corresponding CTA findings. CTA was performed using multidetector computed tomography following intravenous administration of iodinated contrast material. Multiplanar and three-dimensional vascular reconstructions were used to evaluate the carotid arteries for luminal narrowing, atheromatous change, occlusion, and collateral circulation. CTA served as the reference examination against which the diagnostic performance of CDUS was assessed.

Demographic, clinical, and imaging information was recorded on a structured data-collection proforma. Recorded variables included age, sex, body mass index, clinical presentation as stroke or TIA, vascular comorbidities including hypertension, diabetes mellitus, and hyperlipidemia, plaque morphology, stenosis severity, and the findings of CDUS and CTA. Because both imaging modalities were performed in the same study population, diagnostic classification could be directly cross tabulated at the participant level. CDUS results were classified as true positive, true negative, false positive, or false negative according to the corresponding CTA classification.

Data were analyzed using IBM SPSS Statistics version 23.0. Quantitative variables, including age and body mass index, were summarized using means and standard deviations, whereas categorical variables, including sex, comorbidities, clinical presentation, plaque characteristics, and stenosis categories, were summarized as frequencies and percentages. A 2 × 2 contingency table was constructed by comparing CDUS findings with CTA findings. Diagnostic performance was expressed as sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy.

Sensitivity was defined as the proportion of CTA-positive patients correctly identified by CDUS, specificity as the proportion of CTA-negative patients correctly classified by CDUS, positive predictive value as the proportion of CDUS-positive findings confirmed by CTA, negative predictive value as the proportion of CDUS-negative findings without stenosis on CTA, and overall accuracy as the proportion of correctly classified participants among all evaluated participants. Stratified analyses were performed according to selected potential effect modifiers, including age, sex, comorbidities, and severity of stenosis. Statistical significance was evaluated at a two-sided p-value of <0.05.

The study was conducted after ethical approval under reference number CPSP/REU/RAD-2023-045-4123. Written informed consent was obtained from all participants before studying procedures. Participation was voluntary, and patients were informed that refusal to participate would not affect their routine clinical care. Particular attention was given to patient safety before CTA, including assessment for contraindications to identified contrast administration.

RESULTS

A total of 120 patients with cerebral ischemic events were included in the analysis. The mean age was 58.4 ± 10.2 years; 72 (60.0%) participants were male and 48 (40.0%) were female. Hypertension was present in 78 (65.0%) patients, diabetes mellitus in 54 (45.0%), and hyperlipidemia in 42 (35.0%). Ischemic stroke was the presenting cerebral ischemic event in 84 (70.0%) patients, whereas 36 (30.0%) presented with transient ischemic attack (Table 1).

Table 1. Baseline Demographic and Clinical Characteristics of Participants

Characteristic	Total sample (n=120)
Age, years, mean ± SD	58.4 ± 10.2
Male, n (%)	72 (60.0)
Female, n (%)	48 (40.0)
Hypertension, n (%)	78 (65.0)
Diabetes mellitus, n (%)	54 (45.0)
Hyperlipidemia, n (%)	42 (35.0)
Ischemic stroke, n (%)	84 (70.0)
Transient ischemic attack, n (%)	36 (30.0)

SD, standard deviation.

Using CT angiography as the reference standard, carotid artery stenosis was present in 64 (53.3%) patients and absent in 56 (46.7%). Carotid Doppler ultrasonography classified 68 (56.7%) patients as positive and 52 (43.3%) as negative. Among the 64 CTA-positive patients, CDUS correctly identified 60 and missed 4. Among the 56 CTA-negative patients, 48 were correctly classified as negative and 8 were classified as false positive (Table 2).

Table 2. Cross-tabulation of Carotid Doppler Ultrasonography Against CT Angiography

CT angiography	CDUS positive, n (%)	CDUS negative, n (%)	Total, n (%)
Stenosis present	60 (50.0)	4 (3.3)	64 (53.3)
Stenosis absent	8 (6.7)	48 (40.0)	56 (46.7)
Total	68 (56.7)	52 (43.3)	120 (100.0)

Values are n (% of the total sample). CDUS, carotid Doppler ultrasonography; CT, computed tomography.

Based on these paired findings, CDUS demonstrated a sensitivity of 93.8% (95% CI, 85.0–97.5) and specificity of 85.7% (95% CI, 74.3–92.6). The positive predictive value was 88.2% (95% CI, 78.5–93.9), whereas the negative predictive value was 92.3% (95% CI, 81.8–97.0). Overall diagnostic accuracy was 90.0% (95% CI, 83.3–94.2). The positive likelihood ratio was 6.56 (95% CI, 3.44–12.50), while the negative likelihood ratio was 0.07 (95% CI, 0.03–0.19), indicating a substantial increase in the probability of stenosis following a positive CDUS result and a marked reduction following a negative result. The derived diagnostic odds ratio was 90.00 (95% CI, 25.56–316.92) (Table 3).

Table 3. Diagnostic Performance of Carotid Doppler Ultrasonography Using CT Angiography as the Reference Standard

Diagnostic measure	Estimate	95% CI
Sensitivity, %	93.8	85.0–97.5
Specificity, %	85.7	74.3–92.6
Positive predictive value, %	88.2	78.5–93.9
Negative predictive value, %	92.3	81.8–97.0
Overall accuracy, %	90.0	83.3–94.2
Positive likelihood ratio	6.56	3.44–12.50
Negative likelihood ratio	0.07	0.03–0.19
Diagnostic odds ratio	90.00	25.56–316.92

CI, confidence interval. Confidence intervals for proportions were calculated using the Wilson method; likelihood-ratio and diagnostic-odds-ratio confidence intervals were calculated on the logarithmic scale.

Agreement between CDUS and CTA was high, with identical classifications in 108 of 120 patients, corresponding to an observed agreement of 90.0%. Cohen's kappa was 0.80 (95% CI, 0.69–0.91; p<0.001). Among the 12 discordant examinations, 8 were CDUS-positive/CTA-negative and 4 were CDUS-negative/CTA-positive. Exact McNemar testing showed no statistically significant directional difference between the discordant classifications (p=0.388) (Table 4).

Table 4. Agreement Between Carotid Doppler Ultrasonography and CT Angiography

Agreement measure	Estimate	95% CI	p-value
Observed agreement, %	90.0	–	–
Cohen's κ	0.80	0.69–0.91	<0.001
McNemar exact test	–	–	0.388

CI, confidence interval; κ, Cohen's kappa. McNemar testing was based on the 12 discordant paired observations.

Overall, CDUS demonstrated high sensitivity and negative predictive value against CTA, with only 4 of 64 CTA-positive cases classified as negative by CDUS. Specificity was comparatively lower because 8 of 56 CTA-negative patients were classified as positive by CDUS. The likelihood-ratio estimates and substantial inter-modality agreement further support the diagnostic discrimination of CDUS in this study population.

DISCUSSION

The present study found that carotid Doppler ultrasonography demonstrated high diagnostic performance for detecting carotid artery stenosis in patients with recent cerebral ischemic events when CTA was used as the reference standard. The principal finding was the high sensitivity and negative predictive value of CDUS, accompanied by somewhat lower specificity. Agreement between the two imaging modalities was substantial, and the low negative likelihood ratio indicates that a negative CDUS examination substantially reduced the probability of carotid stenosis within this study population. At the same time, the occurrence of false-positive and false-negative classifications indicates that CDUS and CTA should not be regarded as completely interchangeable diagnostic modalities.

The observed diagnostic performance is broadly comparable with previously reported evidence. A Pakistani study involving 85 patients and 170 carotid arteries reported a sensitivity of 92.0%, specificity of 89.0%, and overall diagnostic accuracy of 91.1% for duplex ultrasonography compared with CTA (8). The present study demonstrated a similar sensitivity of 93.8% and overall accuracy of 90.0%, although specificity was somewhat lower at 85.7%. Differences in specificity between studies may reflect variation in the study population, prevalence and spectrum of stenosis, diagnostic thresholds, operator technique, ultrasound equipment, arterial anatomy, and the criteria used to translate Doppler velocity measurements into stenosis categories. Previous studies have shown that peak systolic velocity and other Doppler-derived parameters correlate with angiographic stenosis but that the relationship is not uniform across all grades of disease (9,10).

The findings are also consistent with broader evidence supporting duplex ultrasonography as an effective noninvasive modality for evaluating symptomatic carotid stenosis. Systematic evidence has demonstrated good diagnostic performance of duplex ultrasound, particularly for clinically important degrees of stenosis, while also emphasizing heterogeneity in diagnostic thresholds and study protocols (5). Multimodality imaging studies similarly indicate that ultrasound, CTA, and magnetic resonance angiography each have important strengths and limitations and that discrepancies may arise because ultrasound primarily evaluates hemodynamic consequences of arterial narrowing, whereas CTA provides predominantly anatomical characterization of the arterial lumen and surrounding plaque (11). Accurate grading is also influenced by how stenosis is measured and classified, highlighting the importance of standardized anatomical and hemodynamic criteria when different modalities are compared (12).

The likelihood-ratio estimates provide additional clinical context to the conventional measures of sensitivity and specificity. The positive likelihood ratio of 6.56 indicates that a positive CDUS result meaningfully increases the probability of carotid stenosis, whereas the negative likelihood ratio of 0.07 indicates a marked reduction in probability following a negative examination. However, 8 of 56 CTA-negative patients were classified as positive by CDUS, accounting for the lower specificity and indicating that a positive Doppler result may require anatomical confirmation when subsequent management depends on accurate characterization of the lesion. Conversely, only 4 of 64 CTA-positive cases were classified as negative by CDUS. Because grade-specific information for these discordant examinations was not available from the validated 2 × 2 analysis, the present findings should not be interpreted as demonstrating equivalent sensitivity across mild, moderate, severe, and occlusive disease.

The substantial agreement observed between the two modalities further supports the usefulness of CDUS as an initial vascular assessment tool. Nevertheless, the absence of a statistically significant directional difference between discordant examinations on McNemar testing does not demonstrate equivalence between CDUS and CTA; rather, it indicates that the available paired data did not show systematic predominance of one direction of disagreement. Cross-sectional imaging remains particularly valuable when detailed anatomical characterization is needed, including assessment of complex stenosis or suspected occlusion, because diagnostic disagreement between duplex ultrasound and tomographic angiographic techniques can occur in clinically important cases (13,14).

Several technical factors may explain such discrepancies. CDUS estimates the severity of stenosis primarily through changes in blood-flow velocity and waveform characteristics together with grayscale assessment of the arterial wall and plaque. Measurements can therefore be influenced by insonation angle, vessel tortuosity, altered cardiac output, tandem lesions, near-occlusive flow patterns, calcification, and operator-dependent acquisition. Relationships between peak systolic velocity and angiographic narrowing are consequently strong but imperfect (9,10). CTA, in contrast, directly depicts luminal anatomy and facilitates multiplanar assessment, although heavy calcification, reconstruction technique, and the method used to quantify luminal narrowing can also influence stenosis classification (11,12). These modality-specific characteristics provide a plausible explanation for the observed combination of high overall agreement with a limited number of discordant examinations.

From a clinical perspective, the high sensitivity and negative predictive value observed in this symptomatic population support CDUS as a useful noninvasive first-line investigation where rapid vascular assessment is required. This is relevant because identification of carotid stenosis after ischemic stroke or TIA contributes to risk stratification and subsequent decisions regarding medical therapy and consideration of carotid revascularization in appropriately selected patients (1–4). The findings should not, however, be interpreted as evidence that CDUS alone improves clinical outcomes or can universally replace CTA. Rather, they support a complementary diagnostic pathway in which ultrasound can provide an accessible initial assessment, while cross-sectional angiographic imaging can provide additional anatomical information when results are positive, discordant, technically limited, or likely to influence procedural planning.

The study has several strengths, including the paired evaluation of CDUS and CTA in the same symptomatic patient population, inclusion of 120 participants, and the use of a complete 2 × 2 diagnostic classification that permitted estimation of sensitivity, specificity, predictive values, likelihood ratios, overall accuracy, and intermodality agreement. Nevertheless, several limitations should be considered. The single-center design limits generalizability to institutions with different patient populations, equipment, and operator expertise. Diagnostic ultrasound is inherently operator dependent, and interobserver variability was not quantified. The study population had a relatively high prevalence of CTA-confirmed stenosis, meaning that the reported positive and negative predictive values may not be directly transferable to populations with substantially different disease prevalence. CTA was used as the study reference standard rather than invasive digital subtraction angiography, and no imaging reference standard is entirely free of measurement limitations. In addition, the available validated data did not permit reliable grade-specific diagnostic-accuracy analysis or robust assessment of diagnostic performance across age, sex, plaque morphology, and comorbidity subgroups. These factors should be considered when interpreting the findings beyond the studied population.

Overall, the findings indicate that carotid Doppler ultrasonography provides clinically useful diagnostic discrimination for carotid artery stenosis in patients presenting with cerebral ischemic events, particularly because of its high sensitivity and ability to reduce the probability of disease following a negative examination. Its lower specificity relative to sensitivity and the presence of discordant examinations reinforce the complementary role of CTA when precise anatomical confirmation is required.

CONCLUSION

Carotid Doppler ultrasonography demonstrated high sensitivity, good specificity, and substantial agreement with CT angiography for detecting carotid artery stenosis in patients with cerebral ischemic events, with an overall diagnostic accuracy of 90.0%. These findings support CDUS as a useful noninvasive initial assessment modality, particularly for identifying patients unlikely to have stenosis, while CTA remains valuable when anatomical confirmation and precise characterization of carotid disease are required.

REFERENCES

1. Naylor AR, Rantner B, Ancetti S, et al. Editor's Choice – European Society for Vascular Surgery (ESVS) 2023 clinical practice guidelines on the management of atherosclerotic carotid and vertebral artery disease. Eur J Vasc Endovasc Surg. 2023;65(1):7–111. doi:10.1016/j.ejvs.2022.04.011.
2. AbuRahma AF, Avgerinos ED, Chang RW, et al. Society for Vascular Surgery clinical practice guidelines for management of extracranial cerebrovascular disease. J Vasc Surg. 2022;75(1S):1S–122S. doi:10.1016/j.jvs.2021.04.073.
3. Kleindorfer DO, Towfighi A, Chaturvedi S, et al. 2021 guideline for the prevention of stroke in patients with stroke and transient ischemic attack. Stroke. 2021;52(7):e364–e467. doi:10.1161/STR.0000000000000375.
4. Bonati LH, Kakkos S, Berkefeld J, et al. European Stroke Organisation guideline on endarterectomy and stenting for carotid artery stenosis. Eur Stroke J. 2021;6(2):I–XLVII. doi:10.1177/23969873211012121.
5. Cassola N, Mota AS, Libânio MML, et al. Duplex ultrasound for diagnosing symptomatic carotid stenosis in the extracranial segments. Cochrane Database Syst Rev. 2022;9:CD013172. doi:10.1002/14651858.CD013172.pub2.
6. Zeng HL, Lin YC, Wang Y, et al. Systematic review and meta-analysis of the diagnostic value of carotid vascular ultrasound, CT angiography, and magnetic resonance imaging in carotid artery stenosis. BMC Med Imaging. 2024;24. doi:10.1186/s12880-024-01390-6.
7. Daolio M, Ferreira DCC, da Silva ASS, et al. Diagnostic accuracy of duplex ultrasonography versus computed tomographic angiography in the detection of significant carotid artery atherosclerosis. Rev Col Bras Cir. 2024;51:e20243632. doi:10.1590/0100-6991e-20243632-en.
8. Aziz I, Nafees M, Mohsin I, Shabana. Diagnostic accuracy of duplex ultrasonography versus computed tomographic angiography in the detection of significant carotid artery atherosclerosis. Pak Armed Forces Med J. 2024;74(1). doi:10.51253/pafmj.v74i1.8560.
9. Pakizer D, Goudarzi S, Alizadeh A, et al. Peak systolic velocity ratio for evaluation of internal carotid artery stenosis correlated with plaque morphology: substudy results of the ANTIQUE study. Front Neurol. 2023;14:1206483. doi:10.3389/fneur.2023.1206483.
10. Tătaru DA, Olinic M, Homorodean C, et al. Correlation between ultrasound peak systolic velocity and angiography for grading internal carotid artery stenosis. J Clin Med. 2024;13(2):517. doi:10.3390/jcm13020517.
11. David E, Grazhdani H, Aliotta L, et al. Imaging of carotid stenosis: where are we standing? Comparison of multiparametric ultrasound, CT angiography, and MRI angiography, with recent developments. Diagnostics (Basel). 2024;14(16):1708. doi:10.3390/diagnostics14161708.
12. Saba L, Balestrieri A, Di Martino M, et al. Quantifying carotid stenosis: history, current applications, and future directions. Life (Basel). 2024;14(1):73. doi:10.3390/life14010073.
13. Speranza G, Harish K, Rockman C, et al. Duplex ultrasound and cross-sectional imaging in carotid artery occlusion diagnosis. J Vasc Surg. 2024;79(3):577–583. doi:10.1016/j.jvs.2023.11.029.
14. Rau S, Strecker C, Russe MF, et al. Assessing internal carotid artery stenosis: diagnostic value of photon-counting detector CT angiography compared to Doppler ultrasound. Eur J Radiol. 2025;191:112338. doi:10.1016/j.ejrad.2025.112338.