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DIAGNOSTIC ACCURACY OF CAROTID DOPPLER ULTRASOUND FOR DIAGNOSIS OF CAROTID STENOSIS TAKING COMPUTED TOMOGRAPHY ANGIOGRAPHY AS A GOLD STANDARD

Original Research

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ABSTRACT

Background: Carotid artery stenosis, resulting from atherosclerotic narrowing of the carotid arteries, is a major cause of ischemic stroke and transient ischemic attacks. Early and accurate diagnosis of this condition is essential to prevent cerebrovascular complications. Carotid Doppler ultrasound (CDUS) and computed tomography angiography (CTA) are commonly used imaging modalities for detecting carotid stenosis, with CTA regarded as the gold standard. This study aimed to assess the diagnostic accuracy of CDUS in detecting carotid artery stenosis using CTA as the reference standard.

Objective: To determine the diagnostic accuracy, sensitivity, specificity, and predictive values of carotid Doppler ultrasound for the detection of carotid artery stenosis, using computed tomography angiography as the gold standard.

Methods: This cross-sectional validation study was conducted in the Radiology Department of Khyber Teaching Hospital, Peshawar, over six months following ethical approval. A total of 125 patients aged 25–80 years with symptoms suggestive of carotid stenosis were enrolled through non-probability consecutive sampling. Each patient underwent both CDUS and CTA. Findings from both modalities were compared to calculate sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy. Data were analyzed using IBM SPSS v27, with $p \leq 0.05$ considered statistically significant.

Results: The mean age of participants was 58.7 ± 10.9 years, with 60.8% males. Carotid stenosis was detected in 28.8% of patients on CDUS and 27.2% on CTA. CDUS showed a sensitivity of 88.2%, specificity of 93.4%, PPV of 83.3%, NPV of 95.6%, and overall diagnostic accuracy of 92.0%. The prevalence of stenosis was higher among smokers, hypertensive, and diabetic patients.

Conclusion: Carotid Doppler ultrasound demonstrated high diagnostic accuracy compared to computed tomography angiography, supporting its role as a reliable, non-invasive, and cost-effective screening tool for carotid artery stenosis in clinical practice.

Keywords: Atherosclerosis, Carotid Artery Diseases, Carotid Doppler Ultrasound, Carotid Stenosis, Computed Tomography Angiography, Diagnostic Accuracy, Stroke, Ultrasonography.

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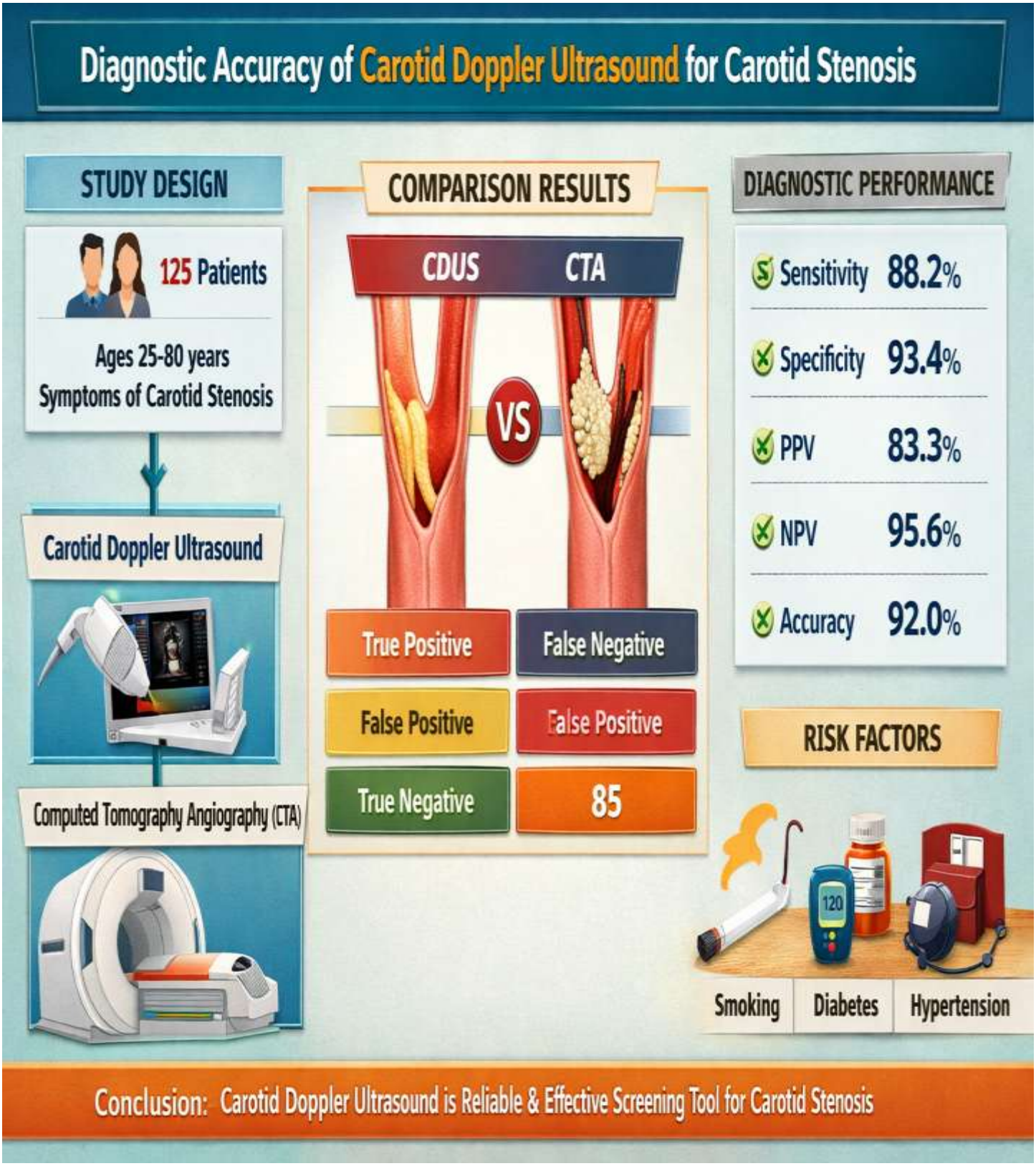

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INTRODUCTION

Carotid artery stenosis, characterized by the narrowing of the carotid arteries that supply oxygenated blood to the brain, remains a major risk factor for ischemic stroke, one of the leading causes of morbidity and mortality worldwide (1). The condition arises primarily due to systemic atherosclerotic disease, in which plaque buildup progressively narrows the arterial lumen, compromising cerebral blood flow and predisposing individuals to cerebrovascular events (2). Consequently, any risk factor associated with atherosclerosis—such as hypertension, diabetes mellitus, dyslipidemia, and smoking—can contribute to the development and progression of carotid stenosis, ultimately leading to ischemic stroke or transient ischemic attack–like symptoms (3,4). Clinically, carotid stenosis may present with typical ischemic manifestations or with hemodynamic symptoms that are more variable and subtle in nature (5). Patients may experience transient ischemic attacks, limb shaking, retinal claudication, headache resulting from extensive collateral circulation via the external carotid artery, syncope, or generalized fatigue (6). Timely recognition of these symptoms is vital, as immediate revascularization is often indicated in acute symptomatic carotid occlusion, particularly when symptoms appear abruptly (7). Epidemiological evidence underscores the disease burden, with one study reporting that among 261 patients, 52% had bilateral carotid stenosis, 19.5% had unilateral involvement, and a significant association was observed with smoking, affecting 55.8% of those with stenosis (8). The mean age in this cohort was 61.6 ± 11.3 years, highlighting the mid-to-late adulthood predilection of the disease.

Accurate diagnosis of carotid stenosis is crucial to prevent irreversible neurological damage. Carotid Doppler ultrasound (CDUS) has emerged as a preferred initial imaging modality due to its non-invasive nature, affordability, and real-time visualization capabilities (9). Utilizing high-frequency sound waves, CDUS allows for the assessment of luminal narrowing, plaque morphology, and hemodynamic parameters by measuring flow velocities and ratios within the internal and common carotid arteries (6). In comparison, Computed Tomography Angiography (CTA) employs advanced cross-sectional imaging to provide high-resolution visualization of the carotid vasculature, enabling precise anatomical characterization of stenotic segments and calcified plaques (10). Despite its superior anatomical detail, CTA exposes patients to ionizing radiation and contrast agents, making CDUS a safer and more practical first-line tool in many clinical scenarios (11). Several studies have attempted to evaluate the diagnostic accuracy of CDUS against CTA, reporting varying results. One study observed a frequency of carotid stenosis of 28.92% among adults and found CDUS to have a sensitivity of 89.5% and specificity of 76.2% for detecting carotid stenosis (12,13). These findings emphasize the need for continued evaluation of CDUS performance relative to gold-standard imaging techniques, particularly within different clinical settings and operator-dependent environments. Given the clinical significance of early and accurate diagnosis, this study aims to determine the diagnostic accuracy of carotid Doppler ultrasound in detecting carotid stenosis, taking computed tomography angiography as the gold standard. The rationale for this objective lies in enhancing diagnostic reliability, optimizing imaging protocols, and guiding clinicians in adopting CDUS as a dependable, non-invasive tool for screening and initial assessment of patients with suspected carotid artery disease.

METHODS

The present study was designed as a cross-sectional validation study conducted in the Department of Radiology at Khyber Teaching Hospital, Medical Teaching Institute (MTI), Peshawar. The study was carried out over a minimum duration of six months following approval of the synopsis by the College of Physicians and Surgeons Pakistan (CPSP) and the institutional ethical review board (IRB). All participants were informed about the objectives, benefits, and voluntary nature of their participation, and written informed consent was obtained prior to inclusion in the study, ensuring full compliance with ethical standards and the Declaration of Helsinki. The sample size was calculated using the WHO sample size calculator, based on the assumptions that the frequency of carotid stenosis among adult patients was 28.92% (12), with a sensitivity of 89.5% and specificity of 76.2% for carotid Doppler ultrasound in detecting carotid stenosis (13), at an absolute precision of 10% and a 95% confidence level. The final calculated sample size was 125 participants. A non-probability consecutive sampling technique was employed to recruit eligible patients. Participants aged between 25 and 80 years of both genders were included if they presented with clinical symptoms suggestive of carotid stenosis, such as blurred vision or transient vision loss, memory loss, and unilateral numbness or weakness. Exclusion criteria comprised patients with known allergies to contrast agents, pregnant women, and those with chronic renal or hepatic disease to minimize the risk associated with contrast-enhanced imaging. Following recruitment, demographic data including age, gender, body mass index (BMI), education level, occupation, socioeconomic status, and residential area were recorded using a structured proforma. Relevant clinical information, including comorbid conditions such as diabetes mellitus, hypertension, and smoking history, was also documented. Each participant underwent carotid Doppler ultrasound (CDUS) examination using a Mitsubishi e-HD ultrasound system equipped with a 7 MHz linear-array transducer. The

sonographic evaluation was performed by an experienced radiologist with at least five years of post-fellowship experience. Standardized parameters including peak systolic velocity (PSV), end-diastolic velocity (EDV), internal carotid artery to common carotid artery (ICA/CCA) ratio, and degree of luminal reduction were measured to assess the presence of carotid stenosis, which was defined as meeting any two of the following criteria: PSV >140 cm/s, EDV >125 cm/s, ICA/CCA ratio >3, or >50% reduction in ICA diameter.

Subsequently, all patients underwent Computed Tomography Angiography (CTA) to confirm the diagnosis, which served as the gold standard. CTA images were evaluated for focal luminal narrowing and the presence of calcified plaques, defined as hyperdense structures exceeding 130 Hounsfield Units within the vessel wall. Both imaging modalities were interpreted independently to avoid observer bias, and the findings were compared to determine the diagnostic accuracy of CDUS in identifying carotid stenosis. Data were analyzed using IBM SPSS Statistics version 27. The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous data such as age, height, weight, and BMI were expressed as mean ± standard deviation (SD) or median with interquartile range (IQR), depending on the distribution. Categorical variables including gender, comorbidities, and imaging findings were summarized as frequencies and percentages. Diagnostic accuracy parameters—sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy—were calculated using a 2×2 contingency table, taking CTA as the reference standard. Stratification of diagnostic accuracy was performed according to potential effect modifiers such as age, gender, BMI, diabetes, hypertension, smoking status, education, occupation, socioeconomic status, and place of residence. Post-stratification comparisons were made using the Chi-square test or Fisher's exact test, with a p-value ≤0.05 considered statistically significant. Results were presented in tabulated form for clarity and ease of interpretation. The diagnostic accuracy of carotid Doppler ultrasound was determined using the following formulas: Sensitivity = A/(A+C) × 100; Specificity = D/(B+D) × 100; Positive Predictive Value = A/(A+B) × 100; Negative Predictive Value = D/(C+D) × 100; and Overall Diagnostic Accuracy = (A+D)/Total Patients × 100. Here, A represented true positives, B false positives, C false negatives, and D true negatives.

RESULTS

The mean age of participants was 58.7 ± 10.9 years, with a male predominance (60.8%). The mean BMI was 27.4 ± 3.8 kg/m². Most participants belonged to the middle socioeconomic group (46.4%), while 63.2% were employed. Urban residents represented 57.6% of the study population. Regarding education, 41.6% had higher education. Smoking was reported in 52.8% of participants, diabetes in 38.4%, and hypertension in 48.8%. Carotid Doppler ultrasound detected carotid stenosis in 36 patients (28.8%), whereas CTA confirmed stenosis in 34 patients (27.2%). The cross-tabulation revealed 30 true positives, 6 false positives, 4 false negatives, and 85 true negatives. Based on these findings, the sensitivity of CDUS was 88.2%, specificity 93.4%, positive predictive value 83.3%, negative predictive value 95.6%, and overall diagnostic accuracy 92.0%. Stratified analysis by risk factors showed that the prevalence of carotid stenosis was higher among smokers (39.4%) compared to non-smokers (60.6%), among diabetics (31.3%) compared to non-diabetics (68.7%), and among hypertensive patients (41.0%) compared to normotensive individuals (59.0%). These findings indicate a strong diagnostic concordance between CDUS and CTA, with CDUS demonstrating high sensitivity and specificity for the detection of carotid stenosis in this patient population.

Table 1: Demographic Characteristics of Study Participants (n = 125)

Variable	Categories	Values
Age (years)	Mean ± SD	58.7 ± 10.9
Gender	Male	76
	Female	49
BMI (kg/m²)	Mean ± SD	27.4 ± 3.8
Socioeconomic Status	Lower	40
	Middle	58
	Upper	27

Variable	Categories	Values
Occupation Status	Employed	79
	Unemployed	46
Residence	Rural	53
	Urban	72
Education	Primary	32
	Middle	41
	Higher	52
Smoking	Yes	66
	No	69
Diabetes	Yes	48
	No	77
Hypertension	Yes	61
	No	64

Table 2: Carotid Stenosis Detection by Imaging Modality (n = 125)

Diagnostic Tool	Carotid Stenosis Present (n, %)	Carotid Stenosis Absent (n, %)
Carotid Doppler Ultrasound	36 (28.8%)	89 (71.2%)
Computed Tomography Angiography	34 (27.2%)	91 (72.8%)

Table 3: Diagnostic Accuracy of Carotid Doppler Ultrasound (Taking CTA as Gold Standard)

Parameter	Values
True Positive (A)	30
False Positive (B)	6
False Negative (C)	4
True Negative (D)	85
Sensitivity	88.2%
Specificity	93.4%
Positive Predictive Value	83.3%
Negative Predictive Value	95.6%
Overall Diagnostic Accuracy	92.0%

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Table 4: Carotid Stenosis According to Risk Factors (n = 125)

Risk Factor	With Stenosis (n, %)	Without Stenosis (n, %)
Smoking	26 (39.4%)	40 (60.6%)
Diabetes	20 (31.3%)	44 (68.7%)
Hypertension	25 (41.0%)	36 (59.0%)

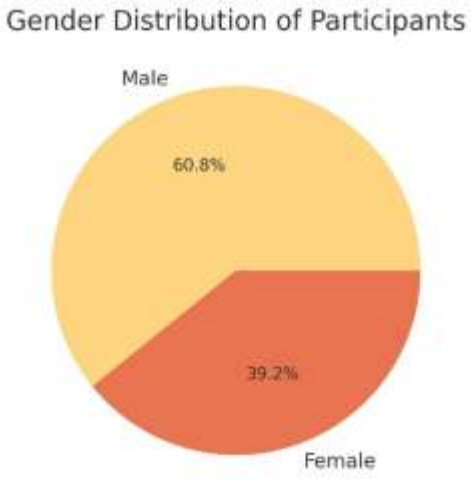

Figure 2 Gender Distribution of Participants

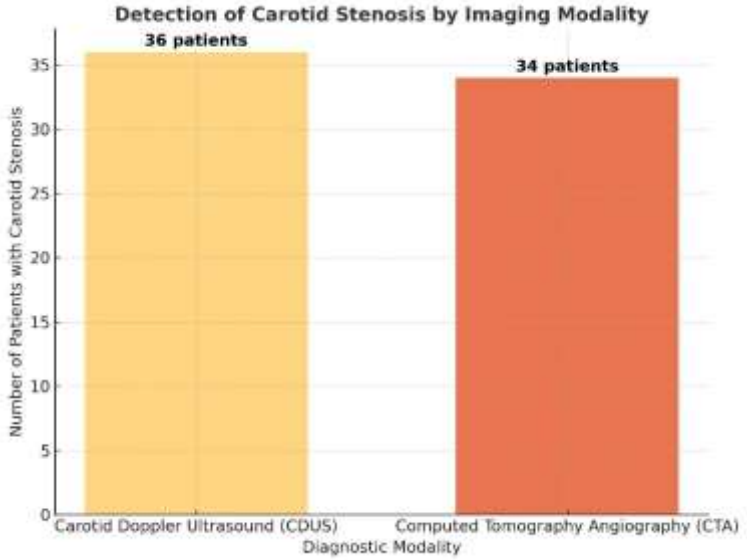

Figure 2 Detection of Carotid Stenosis by Imagine Modality

DISCUSSION

The results of this study demonstrated that carotid Doppler ultrasound (CDUS) exhibited high diagnostic accuracy when compared with computed tomography angiography (CTA) in the detection of carotid artery stenosis among the study cohort. The sensitivity and specificity of CDUS were 88.2% and 93.4%, respectively, with positive and negative predictive values of 83.3% and 95.6%, and an overall diagnostic accuracy of 92.0%. These findings indicate that CDUS correctly identified the majority of patients with and without carotid stenosis when benchmarked against CTA, suggesting that CDUS is a reliable initial diagnostic tool in this clinical setting. The demographic profile of the study participants provided important context for interpreting these outcomes. The mean age of the cohort was 58.7 ± 10.9 years with a predominance of male participants. Common vascular risk factors such as smoking (52.8%), hypertension (48.8%), and diabetes mellitus (38.4%) were prevalent, consistent with known epidemiological patterns for atherosclerotic disease and cerebrovascular risk. These risk factors may contribute to the observed prevalence of carotid stenosis and underline the clinical relevance of accurate imaging in populations with significant vascular comorbidities. Comparative analysis with recent literature demonstrated congruence with prevailing evidence that duplex ultrasound yields high sensitivity and specificity for carotid stenosis when compared with advanced imaging modalities (13,14). A recent diagnostic accuracy study reported that CDU exhibited sensitivity of 91% and specificity of 77% against CTA, with a similarly high negative predictive value, reinforcing ultrasound's role as an effective screening modality in clinical practice (15). Meta-analyses have also highlighted a broad range of reported sensitivities (57–94%) and specificities (87–98%) for CDUS compared to CTA, indicating consistent performance across varied clinical settings and patient populations (16). These ranges align with the present study's estimates and highlight the general robustness of CDUS as an investigational method.

The current findings also echo evidence from systematic reviews suggesting that CTA itself demonstrates excellent sensitivity and specificity for severe internal carotid artery stenosis, often exceeding 90% (17). While CTA remains an important confirmatory imaging tool due to its superior spatial resolution and ability to characterize plaque morphology, its use is constrained by ionizing radiation

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exposure and the need for iodinated contrast, factors that are less concerning with CDUS (18,19). The combination of these imaging modalities—CDUS for initial screening followed by CTA for definitive anatomical characterization—is increasingly advocated in clinical guidelines and supported by evidence emphasizing the complementary strengths of each technique. Despite these strengths, several limitations inherent to CDUS were reinforced by both the study results and existing literature. Ultrasound interpretation is inherently operator dependent, and variability in scanning techniques and diagnostic criteria can influence diagnostic performance, particularly in moderate degrees of stenosis or in vessels with heavy calcification (20,21). Such variability underscores the utility of standardized scanning protocols and comprehensive operator training to enhance reliability across practitioners and institutions. In addition, while CDUS demonstrated high negative predictive value in the study, its positive predictive value was comparatively lower—indicating that a proportion of positive findings may require further verification with CTA or other imaging to guide clinical decisions including revascularization.

The present analysis had methodological strengths that strengthened the validity of its conclusions. A clearly defined reference standard (CTA) was used for diagnostic comparison, and the structured proforma ensured systematic capture of clinical and demographic variables. Stratification by risk factors like smoking and diabetes provided additional insight into population subgroups at higher risk of stenosis. Nonetheless, limitations related to study design should be acknowledged. As a cross-sectional validation study in a single tertiary care center, the findings may not be fully generalizable to broader or asymptomatic populations. Future research could benefit from multicenter designs, larger sample sizes, and inclusion of long-term clinical outcomes to further contextualize diagnostic performance relative to stroke risk and therapeutic outcomes (22,23). In summary, this study confirmed that CDUS exhibits high diagnostic accuracy in detecting carotid stenosis, supporting its role as a first-line imaging modality in at-risk populations. The findings align with contemporary evidence advocating for the integration of both ultrasonography and CTA in diagnostic pathways to optimize patient care while balancing resource utilization and patient safety. Future research should focus on refining ultrasound criteria, integrating emerging imaging biomarkers, and evaluating cost-effectiveness in diverse clinical settings.

CONCLUSION

This study demonstrated that carotid Doppler ultrasound possesses high diagnostic accuracy, sensitivity, and specificity when compared with computed tomography angiography for detecting carotid artery stenosis. Given its non-invasive nature, cost-effectiveness, and absence of radiation exposure, it serves as an excellent first-line imaging modality for screening and initial evaluation of patients at risk of cerebrovascular disease. The findings reinforce the clinical value of carotid Doppler ultrasound in timely diagnosis and management planning, contributing to improved stroke prevention strategies and better patient outcomes.

AUTHOR CONTRIBUTIONS

Author	Contribution
Aisha Iqbal	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Hina Gul*	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Raina Gul	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Nida Ghassan	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published

Author	Contribution
Muhammad Khadim	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published

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