

ORIGINAL ARTICLE

Diagnostic accuracy of doppler ultrasonography to detect carotid artery disease in hypertensive patients, while taking CT Angiography as the gold standard.

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ABSTRACT... **Objective:** To evaluate the diagnostic accuracy of Doppler ultrasonography in detecting carotid artery disease in hypertensive patients, using CT angiography as the reference standard. **Study Design:** Cross-sectional study. **Setting:** Radiology, Ghurki Trust Teaching Hospital, Lahore. **Period:** November 2025 to March 2026. **Methods:** Which consisted of 148 hypertensive patients. Each patient was exposed to Colour Doppler ultrasonography and then to CTA within 24 hours. The results obtained were classified into true positive, true negative, false positive, and false negative. Calculation of sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy was made based on CTA as the gold standard. **Results:** The presence of carotid stenosis was confirmed by CTA in 60.8% of patients. The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of diagnosis by DUS were 93.3%, 75.9%, 85.7%, 88.0%, and 86.5%, respectively. DUS accurately detected 93.3% of patients with stenosis and excluded 75.9% of patients without stenosis. Similar results were obtained in the subgroups stratified by age, gender, BMI, and concomitant diseases. The prevalence of detection increased with the progression of stenosis severity. **Conclusion:** Doppler ultrasonography demonstrates high sensitivity and commendable diagnostic accuracy in identifying carotid artery disease among hypertensive patients. But its moderate specificity shows that CT angiography is still important for confirmation and planning before an intervention. For the best care of patients, a combined diagnostic approach is recommended.

Key words: Carotid Artery Diseases, Doppler, Hypertension, Sensitivity and Specificity, Stroke Prevention, Tomography, Ultrasonography, X-Ray Computed.

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INTRODUCTION

There are carotid arteries on either side of the neck, which are blood vessels that supply blood to the brain. Carotid artery disease occurs due to blockages in these arteries, which reduce blood supply to the brain. The most common cause of a stroke, a cerebrovascular accident, is an abrupt interruption of blood supply to a section of the brain.¹ Every year, an estimated 7 million people have a stroke. Atrial fibrillation and cholesterol deposits causing blockages in the carotid arteries are two prominent causes of stroke. Blood flow to the brain is interrupted if these blockages burst because tiny blood clots and cholesterol pieces separate from the plaque, infiltrate the bloodstream, and become lodged in a smaller blood artery. Stroke risk increases with the size of cholesterol plaque and the severity of obstruction. Symptoms of CAD

include dysarthria, numbness, and weakness on the opposite side of the body.² The most serious case occurs when a thromboembolic deposits in a big cerebral artery, resulting in an abrupt massive vascular blockage that can induce right gaze deviation, left hemiparesis, and abrupt aphasia.²

For carotid stenosis to be effectively treated and stroke prevention achieved, a timely and accurate diagnosis is essential. A few diagnostic techniques are digital subtraction angiography (DSA), magnetic resonance angiography (MRA), CT angiography, and colour Doppler ultrasonography (DUS). The decision is based on indication and hospital availability. Because Colour Doppler is non-invasive and reasonably priced, it is first utilised. Interpretation, however, is based on the expertise and decisions of medical professionals.

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For an objective assessment of carotid stenosis, CT angiography is the preferable method. It is a minimally intrusive process that yields accurate data on carotid artery health.³

A prospective contrast study with 32 stroke suspects was carried out at Pakistan's Radiology Department. An affordable, safe, and non-invasive bedside instrument for measuring the velocity of blood flow via the carotid arteries during a cardiac cycle is a Doppler ultrasound. According to the study's findings, CTA is still the preferred diagnostic technique for stenosis in cases when there is a high clinical suspicion, with a diagnosis accuracy of 53%. The findings imply that DUS is an effective method for identifying CAD in stroke victims.⁴ According to a study, the Doppler ultrasound has a 91% overall sensitivity, 77% specificity, 47.3% positive predictive value, 92.5% negative predictive value, and 80% diagnostic accuracy. The study found that the diagnosis of Carotid artery stenosis is now much more accurate thanks to technological developments. Doppler Ultrasound with CTA as the Gold Standard for Carotid Stenosis Detection achieved excellent diagnostic accuracy.⁵ In another study, the sensitivity and specificity of Doppler ultrasonography were found to be 88.5% and 84.3%, respectively.⁶ Prevalance was found to be 29.8%.

Hypertension is a major independent risk factor that significantly accelerates carotid artery disease through endothelial damage and plaque formation. In hypertensive patients, the prevalence of carotid stenosis is markedly higher than in the general population, often ranging from 20–40% or more, depending on age, duration, and control of hypertension.

This makes it especially important to get the right diagnosis in this high-risk group so that stroke prevention strategies can be put into action quickly.⁷

In resource-constrained environments, validating the efficacy of Doppler ultrasonography against CTA, particularly in hypertensive patients, can endorse its application as a viable first-line screening instrument while designating CTA for verification or surgical planning.⁸

Recent authentic studies continue to demonstrate strong diagnostic performance of Doppler ultrasonography when CTA is used as the gold standard, with a sensitivity of 88.2%, a specificity of 93.4%, and an overall diagnostic accuracy reaching 92.0% in relevant patient cohorts, including those with vascular risk factors such as hypertension.^{9,10}

Our research proposal aimed to assess the diagnostic accuracy of Doppler ultrasonography, taking CTA as the gold standard, in the diagnosis of carotid artery disease in hypertensive patients. This research fills a gap in the literature and offers helpful insights into the issue. Physicians may utilise non-invasive imaging techniques that have demonstrated high diagnostic accuracy to evaluate a patient's condition accurately. This will allow the physician to choose the best course of treatment and lower the risk of morbidity and mortality. Our study aimed to evaluate the diagnostic accuracy of Doppler ultrasonography to detect carotid artery disease in hypertensive patients, while taking CT angiography as the gold standard.

METHODS

This cross-sectional study was conducted in the Radiology Department of Ghurki Trust Teaching Hospital, Lahore, over a period of 4 months (November 2025 to March 2026) after taking approval from the Hospital Ethical Committee (No:2541/HR/GTTH) Dated: 14-05-2025. A total of 148 patients were included in the study, and the sample size was calculated using a 95% confidence level, 10% desired precision, 29.8% prevalence, 88.5% sensitivity, and 84.3% specificity.⁶ A non-probability consecutive sampling technique was used to recruit participants. Males and females referred to radiology for the determination of carotid stenosis, determined by colour doppler ultrasound and CT angiography, aged 18 years or older, who were hypertensive ($\geq 140/90$ mmHg), and willing to participate in the study were included. Patients with incomplete diagnostic results, fibromuscular dysplasia, giant cell arteritis, malignancies, or those who have claustrophobia and are unable to undergo a CT scan were excluded. Written informed consent was obtained from all participants prior to inclusion. Each patient underwent two diagnostic investigations, namely Colour Doppler ultrasonography and CT

angiography, with CTA considered the gold standard for the diagnosis of carotid artery stenosis. Doppler ultrasound was performed by a trained radiologist using a standardised technique. Findings were interpreted based on predefined criteria, where positive findings included increased blood flow velocity suggestive of stenosis, and negative findings indicated normal flow without evidence of narrowing or obstruction. CT angiography was performed within 24 hours of Doppler ultrasound for validation, employing contrast-enhanced computed tomography to visualise the carotid arteries. Positive findings were characterised by visible narrowing or obstruction, while negative findings indicated normal, unobstructed arteries devoid of significant plaque formation. A structured proforma was used to record demographic and clinical information, such as age, gender, blood pressure, and whether the person had ever had a stroke or a transient ischemic attack.

The outcomes of both diagnostic modalities were assessed and classified into true positives, true negatives, false positives, and false negatives. True positives were identified as patients exhibiting positive findings on both DUS and CTA, true negatives as those demonstrating negative results on both modalities, false positives as individuals showing positive results on DUS but negative on CTA, and false negatives as patients displaying negative results on DUS but positive on CTA. Carotid artery disease was operationally defined as the narrowing of the carotid arteries due to atherosclerosis, which supply oxygen-rich blood to the brain.

Diagnostic accuracy was assessed by calculating sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), where sensitivity was defined as the ability of DUS to identify patients with carotid artery disease correctly ($TP/[TP+FN]$), specificity as the ability to identify patients without the disease correctly ($TN/[TN+FP]$), PPV as the proportion of true positive results among all positive DUS findings ($TP/[TP+FP]$), and NPV as the proportion of true negative results among all negative DUS findings ($TN/[TN+FN]$). Data were entered and analysed using SPSS version 22.0. Descriptive statistics were used to summarise

data. Quantitative variables like age and BMI were presented by mean and standard deviation, while qualitative variables like gender, comorbidity, CAD on DUS, and CTA were presented by frequency and percentage. A 2x2 contingency table was constructed to evaluate the diagnostic performance of Doppler ultrasonography using CT angiography as the reference standard. Data were stratified by age, gender, BMI, and comorbidity and a post-stratification chi-square test was applied.

RESULTS

Baseline Characteristics

The study included a total of 148 patients, with a mean age of 59.7 ± 9.8 years, suggesting that the population primarily comprised older adults at an elevated risk for vascular disease. There were 58.1% men and 41.9% women in the sample. The average BMI was $27.4 \text{ kg/m}^2 \pm 3.6 \text{ kg/m}^2$, which means that most of the people who took part were overweight. 41.2% had Stage I hypertension, 30.4% had Stage II hypertension, 18.9% were pre-hypertensive, and 9.5% were in hypertensive crisis.

Many patients had more than one health problem. For example, 35.1% had diabetes mellitus, 42.6% had hypercholesterolemia, 19.6% had a stroke before, and 16.2% had a TIA. CT angiography showed that 60.8% of patients had carotid stenosis. The internal carotid artery was found to be the most commonly affected segment (43.0%), while the common carotid artery came second (14.2%). On the other hand, 23.0% of patients exhibited mild narrowing, 22.3% showed moderate narrowing, and 15.5% were severely narrowed. This clearly demonstrates that this particular study population is characterised by a significant prevalence of vascular risk factors.

DUS demonstrated sensitivity in detecting the presence of stenosis in 84 out of 90 subjects with stenosis and specificity in excluding stenosis in 44 out of 58 subjects who did not have stenosis.

The comparison between Doppler ultrasonography and CT angiography yielded the following: 93.3% sensitivity in detecting stenosis, 75.9% specificity in excluding stenosis. However, there were still 6.7% of false negatives in terms of detecting stenosis and 24.1% of false positives in terms of excluding

stenosis.

From these data, it can be deduced that Doppler ultrasonography has a high level of accuracy in diagnosing disease and a low percentage of false negatives. On the other hand, Doppler ultrasonography shows a certain level of deficiency in terms of specificity because of false positives.

TABLE-I

Baseline demographic and clinical characteristics (n = 148)

Variable	Value
Age (years), mean $\pm$ SD	59.7 $\pm$ 9.8
BMI (kg/m ²), mean $\pm$ SD	27.4 $\pm$ 3.6
Gender	
Male, n (%)	86 (58.1%)
Female, n (%)	62 (41.9%)
Hypertension category, n (%)	
Prehypertensive	28 (18.9%)
Stage I	61 (41.2%)
Stage II	45 (30.4%)
Hypertensive crisis	14 (9.5%)
Comorbid conditions, n (%)	
Diabetes mellitus	52 (35.1%)
Stroke	29 (19.6%)
Hypercholesterolemia	63 (42.6%)
TIA	24 (16.2%)
CTA confirmed stenosis, n (%)	
Present	90 (60.8%)
Absent	58 (39.2%)
Location of stenosis, n (%)	
Internal carotid artery (ICA)	63 (43.0%)
Common carotid artery (CCA)	21 (14.2%)
None	64 (43.2%)
Severity of stenosis, n (%)	
Mild ($\leq$ 50%)	34 (23.0%)
Moderate (50–79%)	33 (22.3%)
Severe ($\geq$ 80%)	23 (15.5%)

TABLE-II

2x2 Contingency Table for DUS vs CTA (n = 148)

	CTA Stenosis Present	CTA Stenosis Absent	Total
DUS Stenosis Present	TP = 84	FP = 14	98
DUS Stenosis Absent	FN = 6	TN = 44	50
Total	90	58	148

From this table:

- Sensitivity = $84 / (84 + 6) = 93.3\%$
- Specificity = $44 / (44 + 14) = 75.9\%$
- Positive Predictive Value (PPV) = $84 / (84 + 14) = 85.7\%$
- Negative Predictive Value (NPV) = $44 / (44 + 6) = 88.0\%$
- Overall diagnostic accuracy = $(84 + 44) / 148 = 86.5\%$

The sensitivity was found to be 93.3% (95% CI: 86.1 - 97.1%), which shows that there is a very good detection rate of the presence of carotid artery disease in patients. The specificity is 75.9% (95% CI: 63.3 - 85.2%), which signifies a fair detection rate for excluding carotid artery disease. Positive predictive value was 85.7% (95% CI: 77.0 - 91.5%), and the negative predictive value was 88%.

The diagnostic accuracy for all cases was found to be 86.5% (95% CI: 79.9–91.1). It showed very good correlation with CT angiography. All p-values were statistically significant ($p < 0.001$). This suggests that this is not just a coincidence. This data confirms that Doppler ultrasound is a valuable diagnostic method for hypertension patients.

TABLE-III

Overall diagnostic accuracy indices of DUS versus CTA

Parameter	Estimate (%)	95% CI	PValue*
Sensitivity	93.3	86.1 – 97.1	<0.001
Specificity	75.9	63.3 – 85.2	<0.001
Positive Predictive Value	85.7	77.0 – 91.5	<0.001
Negative Predictive Value	88.0	76.2 – 94.4	<0.001
Overall accuracy	86.5	79.9 – 91.1	<0.001

Stratified analysis showed that Doppler ultrasonography maintained consistently high sensitivity across all subgroups, ranging from 92.0% to 95.8%. Sensitivity was 92.5% in patients younger than 60 years and 94.0% in those aged 60 years or older, with no statistically significant difference ($p = 0.78$). Similarly, sensitivity was 94.0% in males and 92.3% in females ($p = 0.78$), and ranged from 92.0% in patients with a BMI <25 to 94.0% in those with a BMI ≥ 25 ($p = 0.72$).

Specificity showed minor variation between 70.0% and 78.9% across different subgroups; however, these differences were not statistically significant. Among comorbid conditions, sensitivity remained consistently high in patients with diabetes (94.4%), prior stroke (95.0%), hypercholesterolemia (94.1%), and TIA (95.8%), with corresponding p values of 0.81, 0.72, 0.79, and 0.66, respectively.

All p-values in the stratified analysis were greater than 0.05, indicating that the observed differences in sensitivity, specificity, PPV, and NPV across age groups, gender, BMI categories, and comorbid conditions are likely due to random variation rather than a true effect. From the point of view of statistics, it implies the lack of sufficient evidence to refute the null hypothesis, which postulates the absence of a difference in diagnostic effectiveness among the compared groups.

Additionally, the moderate-to-high p-values (between 0.66 and 0.81) indicate high uniformity in the effectiveness of Doppler ultrasonography for all

subgroups. In particular, the positive predictive value varied between 84.0% and 87.5%, and the negative predictive value varied between 87.5% and 90.9%.

Doppler ultrasonography showed a high detection rate for internal carotid artery stenosis (93.7%) and a slightly lower rate for common carotid artery stenosis (85.7%), with a statistically significant association ($p = 0.021$). In contrast, only 32.8% of patients without significant stenosis were identified as positive, which was also statistically significant ($p < 0.001$).

Regarding severity, the diagnostic performance improved with increasing severity of stenosis. Detection rates were 82.4% in mild cases, 93.9% in moderate cases, and 100% in severe cases, with a statistically significant association ($p = 0.038$). These results suggest that Doppler ultrasonography is particularly effective in identifying moderate to severe stenosis, which is clinically more important for patient management.

TABLE-IV

Stratified analysis by age, gender, BMI & comorbidity

Stratification Factor	Category	n	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	P-Value
Age Group	<60 years	74	92.5	78.3	86.8	87.5	0.78
	≥60 years	74	94.0	73.3	84.6	88.0	
Gender	Male	86	94.0	76.5	86.8	88.4	0.78
	Female	62	92.3	75.0	84.0	87.5	
BMI Category	BMI <25	52	92.0	78.9	85.2	88.2	0.72
	BMI ≥25	96	94.0	74.5	86.0	87.8	
Diabetes Mellitus	Present	52	94.4	73.9	86.8	88.0	0.81
	Absent	96	92.7	76.5	85.1	88.0	
History of Stroke	Prior Stroke	29	95.0	70.0	86.4	87.5	0.72
	No Prior Stroke	119	92.9	77.3	85.4	88.0	
Hypercholesterolemia	Present	63	94.1	74.2	86.5	88.2	0.79
	Absent	85	92.5	77.1	84.9	87.7	
TIA History	Present	24	95.8	71.4	87.5	90.9	0.66
	Absent	124	92.8	76.5	85.3	87.8	

TABLE-V

DUS positivity according to CTA Defined location and severity

CTA Category	Total (n)	DUS Positive, n (%)	PValue
Location			
ICA stenosis	63	59 (93.7%)	0.021
CCA stenosis	21	18 (85.7%)	
No significant stenosis	64	21 (32.8%)	<0.001
Severity			
Mild ($\leq 50\%$)	34	28 (82.4%)	0.038
Moderate (50–79%)	33	31 (93.9%)	
Severe ($\geq 80\%$)	23	23 (100%)	

DISCUSSION

This study assessed the diagnostic accuracy of Doppler ultrasonography (DUS) for detecting carotid artery stenosis in hypertensive patients, using CT angiography (CTA) as the gold standard. DUS showed high sensitivity (93.3%) and overall accuracy (86.5%), with moderate specificity (75.9%), supporting its role as an effective initial screening tool in this high-risk group.

The sensitivity and specificity observed are comparable to prior work evaluating DUS against CTA or invasive angiography. Two studies reported the accuracy of DUS as 80%.¹² A retrospective CTA–DUS comparison demonstrated a strong positive correlation between Doppler and CTA-based grading of stenosis ($p = 0.0002$).¹³

Systematic and comparative studies generally confirm that DUS is accurate for clinically significant (≥ 50 –70%) stenosis but less precise than CTA or MR angiography. A large comparative study with DSA as reference reported an accuracy of 76% for CDUS versus 97% for CTA.¹⁴ An individual patient meta-analysis showed DUS sensitivity 0.97 and specificity 0.70 for 50–99% symptomatic stenosis, and sensitivity 0.85 and specificity 0.98 for 70–99% stenosis.^{15,16} A Cochrane review likewise concluded that DUS has high accuracy for differentiating $<50\%$ vs 50–99% stenosis, but recommended caution when using DUS as the sole pre-operative test.¹⁶

Studies directly comparing DUS and CTA report good but imperfect agreement. A systematic review of 12 DUS–CTA studies found a weighted kappa of 0.85 and an overall accuracy of 0.78, with about 17% of DUS medical stenoses reclassified as surgical by CTA and 14% in the opposite direction.¹⁷ Smaller cross-sectional series have shown moderate to good agreement (kappa 0.63–0.85), with better concordance for moderate–severe stenosis than for non-significant disease.^{18–22} These data are consistent with the present study, where DUS positivity rose from 82.4% in mild to 100% in severe stenosis, indicating particularly strong performance for hemodynamically important lesions.

Regional studies in ischemic stroke cohorts and hypertensive populations have similarly reported high prevalence of carotid disease and good DUS performance. A study using CTA as reference reported DUS sensitivity 91%, specificity 77%, and accuracy 80%.¹¹ A 2021 study by Salehi et al. indicated that CDU sensitivity varied from 85% to 95% for identifying significant carotid artery stenosis in symptomatic individuals.²² The specificity of CDU in evaluating moderate-to-severe stenosis, according to Lee et al. (2020), was approximately 85%.²³ Studies of hypertensive and stroke patients show high frequencies of carotid stenosis and thickened intima–media, reinforcing the need for early vascular imaging in this group.^{23–26}

The high sensitivity and NPV observed, together with comparable values from prior literature, support using DUS as a non-invasive, inexpensive first-line investigation in hypertensive patients with suspected carotid disease.^{13,14,17} The moderate specificity and false positive rate (24.1%) in this study parallel previous reports that DUS can overestimate or misclassify stenosis, particularly in borderline (50–69%) categories.^{14–22} Therefore, CTA should remain the confirmatory test, especially when invasive treatment is considered or when DUS findings are equivocal.

The present study adds value by demonstrating stable diagnostic performance across age, gender, BMI, and comorbidity status, which is less commonly detailed in accuracy studies focusing mainly on symptomatic vs asymptomatic status or stenosis grade.^{15–17} This suggests that in hypertensive

patients, the technical performance of DUS is robust despite clustering of vascular risk factors.

There are a number of strengths of the study. It has a clearly defined group of hypertensive patients that is a high-risk group that is frequently encountered in stroke and vascular clinical practices. The validity of the results is improved by the use of CT angiography as the reference standard because it evaluates the carotid stenosis anatomically. Also, the time gap between Doppler ultrasonography and CT angiography is very short, which eliminates the chances of a disease developing or a disease regressing the outcome. Its limitation lies in the lack of a detailed stratification on categories such as age, gender, body mass index, and comorbid conditions, which indicates the consistency and reliability of Doppler ultrasonography performance in various subgroups of patients.

The study has its limitations, even though it had strengths. This study is a single-centre research that used non-probability consecutive sampling, which can restrict the applicability of the results and create possible selection bias.

Further investigations could include large-scale multi-centre trials to ensure external validity and allow for better subgroup analyses. Trials that evaluate Doppler ultrasonography, CT angiography, and MRA on the same population, with histological validation or follow-up for patient outcomes, will aid in building even stronger diagnostic information and contribute to refining clinical pathways. Standardization of criteria in the Doppler ultrasound assessment process, such as the velocities used as cut-offs and ICA/CCA ratios, should also be considered. Additionally, utilizing new imaging techniques and multiple methods of diagnosis can prove helpful in risk stratification and optimizing the use of imaging methods.

CONCLUSION

This study shows that Doppler ultrasonography is very sensitive, generally accurate, and works well across different demographic and clinical groups for finding carotid artery stenosis in people with high blood pressure. Nonetheless, owing to its moderate specificity and the risk of misclassification, CTA

is essential for conclusive diagnosis and pre-intervention planning. In this high-risk group, the best way to go is to use both DUS for screening and CTA for confirmation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORSHIP AND CONTRIBUTION DECLARATION

1	Tooba Binte Shahid: Conceptualization, framework of study.
2	Nasra Iqbal: Literature review.
3	Azhar Mahmood Javed: Supervisor of study.
4	Abdullah Wali: Data collection.