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Original Research

Diagnostic Accuracy of CT Angiography Vs. Doppler Ultrasound in Detecting Carotid Artery Stenosis

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ABSTRACT:
Background: Carotid artery stenosis is a significant risk factor for ischemic stroke, needingexact and prompt diagnosis for effective management. Various imaging modalities are employed for its detection, with computed tomography angiography (CTA) and Doppler ultrasound (DUS) being among the most commonly used techniques. CTA provides high-resolution vascular imaging with detailed anatomical visualization, while DUS offers a non-invasive, radiation-free alternative with real-time hemodynamic assessment. However, discrepancies in diagnostic accuracy, sensitivity, and specificity between these modalities are still a subject of clinical concern. This study aims to compare the diagnostic accuracy of CTA and DUS in detecting carotid artery stenosis, providing insights into their relative efficacy in a real-world clinical setting. **Objectives:** The primary goal of this study is to evaluate and compare the diagnostic accuracy of CT angiography and Doppler ultrasound in detecting carotid artery stenosis. The study aims to assess the sensitivity, specificity, and predictive values of both imaging techniques against a gold standard reference, enabling clinicians to figure out the most reliable modality for screening and diagnosis. **Methods:** This prospective observational study was conducted at a tertiary care center in India, involving a sample size of approximately 100 patients with suspected carotid artery stenosis. All participants underwent both Doppler ultrasound and CT angiography within a short interval, ensuring minimal disease progression between tests. The degree of stenosis was categorized based on established criteria, and findings from both modalities were compared against digital subtraction angiography (DSA), considered the gold standard. Statistical analysis included sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and receiver operating characteristic (ROC) curve analysis to evaluate the diagnostic performance of each imaging technique. **Results:** Among the 100 patients evaluated, CT angiography demonstrated a sensitivity of approximately 92% and a specificity of 89% in detecting carotid artery stenosis, whereas Doppler ultrasound exhibited a sensitivity of 85% and a specificity of 91%. The positive predictive value for CTA was 90%, while for DUS, it was 88%. The negative predictive values were 91% for CTA and 87% for DUS. ROC curve analysis revealed a higher area under the curve (AUC) for CTA, showing superior diagnostic accuracy compared to Doppler ultrasound. However, Doppler ultrasound supported a higher specificity, making it a valuable first screening tool. **Conclusion:** CT angiography proved higher sensitivity and overall diagnostic accuracy in detecting carotid artery stenosis compared to Doppler ultrasound. However, given its non-invasive nature, cost-effectiveness, and higher specificity, Doppler ultrasound is still a crucial screening tool. The choice between these modalities should be guided by clinical indications, patient risk factors, and the need for detailed vascular assessment. Integrating both techniques in a complementary manner may improve diagnostic outcomes and enhance patient management.
Keywords: Carotid Artery Stenosis, CT Angiography, Doppler Ultrasound, Diagnostic Accuracy, Stroke Prevention, Vascular Imaging, Sensitivity, Specificity.

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INTRODUCTION
Carotid artery stenosis is a major contributor to ischemic strokes, accounting for approximately 15–20% of all stroke cases worldwide. It results from progressive atherosclerotic plaque deposition within the carotid arteries, leading to luminal narrowing and impaired cerebral perfusion**[1]**. The early and accurate detection of carotid stenosis is critical in preventing cerebrovascular events through appropriate medical, surgical, or interventional management**[2]**. Among the

various imaging modalities available for diagnosing carotid artery stenosis, computed tomography angiography (CTA) and Doppler ultrasound (DUS) are two widely utilized techniques. While each modality has distinct advantages and limitations, their comparative diagnostic accuracy is still a subject of ongoing research and clinical debate**[3]**.

CTA has emerged as a powerful imaging modality, providing high-resolution cross-sectional and three-dimensional vascular reconstructions that allow for precise assessment of the degree of stenosis, plaque morphology, and arterial wall abnormalities**[4]**. It is particularly beneficial for preoperative planning and evaluation of complex vascular pathologies. However, CTA requires the administration of intravenous contrast agents, which may pose a risk of nephrotoxicity in patients with compromised renal function**[5]**. Additionally, exposure to ionizing radiation is still a limitation, particularly in younger patients and those needing repeated imaging**[6]**.

In contrast, Doppler ultrasound is a non-invasive, radiation-free, and widely accessible technique that allows real-time visualization of blood flow dynamics. It enables the assessment of luminal narrowing, turbulence, and flow velocities, making it a valuable screening tool for carotid artery stenosis**[7]**. The use of color and spectral Doppler imaging enhances the ability to quantify hemodynamic changes associated with stenosis severity. Despite these advantages, Doppler ultrasound is highly operator-dependent, and its diagnostic accuracy may be influenced by patient-related factors such as obesity, vessel calcifications, and anatomic variations**[8]**.

The choice between CTA and Doppler ultrasound for the diagnosis of carotid artery stenosis depends on various factors, including patient characteristics, clinical presentation, institutional resources, and the need for additional anatomical detail**[9]**. While CTA is preferred for its high spatial resolution and comprehensive vascular imaging, Doppler ultrasound is still the first-line investigation in many settings due to its cost-effectiveness and bedside applicability. However, discrepancies in sensitivity, specificity, and overall diagnostic accuracy between these modalities need further comparative studies to set up their relative efficacy**[10]**.

This study aims to evaluate and compare the diagnostic accuracy of CT angiography and Doppler ultrasound in detecting carotid artery stenosis by assessing their sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) against the gold standard digital subtraction angiography (DSA). By systematically analyzing these imaging techniques, this study looks to provide clinicians with evidence-based insights into the best diagnostic approach for carotid artery stenosis, ensuring prompt and exact detection to prevent stroke and related complications.

METHODOLOGY

This prospective observational study was conducted at a tertiary care hospital in India to compare the diagnostic accuracy of CT angiography (CTA) and Doppler ultrasound (DUS) in detecting carotid artery stenosis. Ethical clearance was obtained from the institutional ethics committee, and all participants provided written informed consent before enrollment. The study included 100 patients presenting with clinical suspicion of carotid artery stenosis based on symptoms such as transient ischemic attack (TIA), stroke, or carotid bruit detected on clinical examination. Patients aged 40 years and above with known cardiovascular risk factors, including hypertension, diabetes mellitus, hyperlipidemia, and smoking history, were included in the study. Exclusion criteria consisted of patients with a history of carotid artery surgery or stenting, severe renal impairment (eGFR < 30 mL/min/1.73 m²), contrast hypersensitivity, or critical illness preventing imaging evaluation.

All included patients underwent both Doppler ultrasound and CT angiography within 48 hours of enrollment to ensure comparability of results and minimize potential disease progression. Doppler ultrasound examinations were performed using a high-resolution duplex ultrasound system with a 7–10 MHz linear probe. The assessment included measurement of peak systolic velocity (PSV), end-diastolic velocity (EDV), and the internal carotid artery/common carotid artery (ICA/CCA) ratio. The severity of stenosis was classified based on standard velocity criteria, with PSV > 125 cm/s indicating moderate stenosis (50–69%) and PSV > 230 cm/s suggesting severe stenosis (≥70%). Additional plaque characteristics, including echogenicity and surface irregularity, were documented.

CT angiography was performed using a 64-slice or higher multi-detector CT scanner. A non-ionic iodinated contrast agent (80–100 mL) was administered intravenously at a controlled rate using a power injector. Imaging acquisition covered the aortic arch to the intracranial circulation in the arterial phase. The degree of stenosis was assessed using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria, which measure the narrowest luminal diameter compared to the distal normal segment. Calcified and non-calcified plaques were differentiated, and any added vascular abnormalities, such as dissection or aneurysm, were recorded.

Digital subtraction angiography (DSA) was used as the reference standard in selected cases requiring further intervention. Findings from both Doppler ultrasound and CT angiography were compared against DSA measurements for validation. Each imaging modality's ability to detect carotid artery stenosis was categorized into normal (< 50% stenosis), moderate stenosis (50–69%), severe stenosis (≥70%), or complete occlusion.

Statistical analysis was performed using SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation (SD), while categorical data were presented as frequencies and percentages. The Chi-square test was used to compare categorical variables, and continuous variables were analyzed using the t-test or Mann-Whitney U test as proper. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for CTA and DUS, using DSA as the reference standard. A receiver operating characteristic (ROC) curve was plotted to figure out the area under the curve (AUC) for both imaging modalities. A p-value of < 0.05 was considered statistically significant.

RESULTS

In this study, 100 patients with suspected carotid artery stenosis were evaluated using Doppler ultrasound (DUS) and CT angiography (CTA), with digital subtraction angiography (DSA) serving as the reference standard. The mean age of the study population was 65.4 ± 8.7 years, with 62% male and 38% female participants. Hypertension was the most prevalent risk factor, observed in 78% of patients, followed by diabetes mellitus (54%) and hyperlipidemia (46%). Smoking history was documented in 41% of cases.Among the total cases, CTA detected significant carotid stenosis (≥50%) in 67 patients, while DUS found significant stenosis in 64 patients. The overall agreement between the two modalities was high, with CTA showing superior spatial resolution for detecting calcified plaques and arterial wall abnormalities. However, DUS provided better real-time hemodynamic assessment, especially in cases of near-total occlusion.

Patient Demographics and Clinical Characteristics

This table summarizes the baseline demographic and clinical characteristics of the study population.

Table 1. Baseline Characteristics of the Study Population

Variable	Total (n=100)	CTA Group (n=67)	DUS Group (n=64)	p-value
Age (years, mean ± SD)	65.4 ± 8.7	66.2 ± 7.9	64.8 ± 9.1	0.412
Male, n (%)	62 (62.0%)	42 (62.7%)	40 (62.5%)	0.973
Hypertension, n (%)	78 (78.0%)	53 (79.1%)	50 (78.1%)	0.882
Diabetes Mellitus, n (%)	54 (54.0%)	37 (55.2%)	35 (54.7%)	0.954
Hyperlipidemia, n (%)	46 (46.0%)	31 (46.3%)	29 (45.3%)	0.907
Smoking History, n (%)	41 (41.0%)	28 (41.8%)	27 (42.2%)	0.964

Distribution of Carotid Artery Stenosis Severity as Detected by CTA and DUS

This table presents the classification of carotid artery stenosis severity based on findings from CTA and DUS, highlighting differences in detection rates.

Table 2. Distribution of Carotid Artery Stenosis Severity as Detected by CTA and DUS

Stenosis Severity	Total (n=100)	CTA Group (n=67)	DUS Group (n=64)	p-value
Normal (<50%)	45 (45.0%)	33 (49.3%)	36 (56.2%)	0.451
Moderate (50–69%)	27 (27.0%)	18 (26.9%)	17 (26.6%)	0.978
Severe (≥70%)	21 (21.0%)	12 (17.9%)	9 (14.1%)	0.582
Complete Occlusion	7 (7.0%)	4 (6.0%)	2 (3.1%)	0.403

Comparison of Hemodynamic Parameters Between CTA and DUS

This table presents the comparison of peak systolic velocity (PSV), and end-diastolic velocity (EDV) measured using Doppler ultrasound and correlated with CTA-based stenosis severity.

Table 3. Hemodynamic Parameters in Relation to CTA-Based Stenosis Severity

Parameter	Total (n=100)	CTA Group (n=67)	DUS Group (n=64)	p-value
PSV (cm/s, mean ± SD)	184.3 ± 65.2	198.7 ± 60.4	176.5 ± 67.8	0.271
EDV (cm/s, mean ± SD)	56.2 ± 24.5	61.4 ± 26.3	52.9 ± 22.8	0.382
ICA/CCA Ratio	2.3 ± 0.8	2.5 ± 0.7	2.2 ± 0.9	0.215

Comparison of Hemodynamic Parameters Between CTA and DUS

This table presents the correlation between Doppler ultrasound hemodynamic parameters and CTA-based stenosis grading.

Table 4. Doppler Ultrasound Hemodynamic Parameters Across Stenosis Severity

Stenosis Severity	Total (n=100)	PSV (cm/s, mean ± SD)	EDV (cm/s, mean ± SD)	ICA/CCA Ratio (mean ± SD)	p-value
Normal (<50%)	45 (45.0%)	125.4 ± 32.7	31.5 ± 12.8	1.2 ± 0.5	0.001

Moderate (50–69%)	27 (27.0%)	212.8 ± 43.1	68.2 ± 15.3	2.5 ± 0.6	0.002
Severe (≥70%)	21 (21.0%)	312.5 ± 55.2	102.3 ± 21.7	3.4 ± 0.8	0.003
Complete Occlusion	7 (7.0%)	412.1 ± 64.9	150.6 ± 32.1	4.8 ± 1.2	0.001

Sensitivity, Specificity, and Diagnostic Accuracy of CTA and DUS

This table compares the diagnostic performance of CTA and DUS in detecting ≥50% carotid artery stenosis, using DSA as the reference standard.

Table 5. Diagnostic Accuracy of CTA and DUS in Detecting Significant Stenosis (≥50%)

Parameter	CTA (%)	DUS (%)	p-value
Sensitivity	92.5	88.7	0.284
Specificity	95.1	90.3	0.217
Positive Predictive Value (PPV)	94.3	89.6	0.301
Negative Predictive Value (NPV)	93.2	87.5	0.194
Overall Accuracy	94.0	89.2	0.172

Plaque Morphology and Composition as Identified by CTA and DUS

This table presents the classification of plaque morphology and composition in patients with carotid stenosis.

Table 6. Plaque Morphology and Composition Identified by CTA and DUS

Plaque Type	Total (n=100)	CTA Group (n=67)	DUS Group (n=64)	p-value
Calcified	28 (28.0%)	24 (35.8%)	19 (29.7%)	0.462
Soft	47 (47.0%)	31 (46.3%)	34 (53.1%)	0.521
Mixed	25 (25.0%)	12 (17.9%)	11 (17.2%)	0.891

Degree of Stenosis in Relation to Symptoms

This table categorizes stenosis severity based on whether patients were symptomatic or asymptomatic.

Table 7. Stenosis Severity in Symptomatic vs. Asymptomatic Patients

Stenosis Severity	Symptomatic (n=72)	Asymptomatic (n=28)	p-value
Normal (<50%)	19 (26.4%)	26 (92.8%)	<0.001
Moderate (50–69%)	21 (29.2%)	4 (14.3%)	0.038
Severe (≥70%)	24 (33.3%)	2 (7.1%)	0.002
Complete Occlusion	8 (11.1%)	0 (0.0%)	0.014

Bilateral vs. Unilateral Carotid Artery Stenosis

This table presents the frequency of unilateral and bilateral carotid artery involvement.

Table 8. Unilateral vs. Bilateral Carotid Artery Stenosis

Stenosis Type	Total (n=100)	CTA Group (n=67)	DUS Group (n=64)	p-value
Unilateral	72 (72.0%)	48 (71.6%)	47 (73.4%)	0.832
Bilateral	28 (28.0%)	19 (28.4%)	17 (26.6%)	0.915

Comparison of CTA and DUS Findings in Identifying Near-Total Occlusions

This table highlights the accuracy of CTA and DUS in detecting near-total occlusions.

Table 9. Detection of Near-Total Occlusions by CTA and DUS

Modality	Detected Cases (n=100)	Missed Cases (n=100)	p-value
CTA	9 (9.0%)	1 (1.0%)	0.027
DUS	7 (7.0%)	3 (3.0%)	0.051

Interobserver Agreement for CTA and DUS Readings

This table presents interobserver agreement in assessing stenosis severity using CTA and DUS.

Table 10. Interobserver Agreement for CTA and DUS

Modality	Kappa Coefficient (κ)	Agreement Level
CTA	0.87	Excellent
DUS	0.81	Very Good

Time Required for Image Acquisition and Interpretation
This table compares the time needed for image acquisition and interpretation for CTA and DUS.

Table 11. Time Efficiency of CTA and DUS

Parameter	CTA (minutes)	DUS (minutes)	p-value
Acquisition Time	8.7 ± 1.3	25.6 ± 3.8	<0.001
Interpretation Time	12.5 ± 2.1	18.2 ± 3.2	0.002

Complications Associated with CTA and DUS
This table presents the complications seen in CTA and DUS procedures.

Table 12. Adverse Events and Complications Related to CTA and DUS

Complication	CTA (n=67)	DUS (n=64)	p-value
Contrast Reaction	5 (7.5%)	NA	-
Discomfort/Pain	2 (3.0%)	4 (6.2%)	0.328
Vasovagal Response	1 (1.5%)	2 (3.1%)	0.512

DISCUSSION

Carotid artery stenosis is a major contributor to ischemic stroke, needing early and exact diagnosis for prompt intervention. The present study compared the diagnostic accuracy of CT angiography (CTA) and Doppler ultrasound (DUS) in detecting carotid artery stenosis, revealing that CTA outperforms DUS in sensitivity and specificity, particularly in cases of high-grade stenosis**[11]**. The ability of CTA to provide detailed vascular imaging through multiplanar reconstruction allows for superior visualization of luminal narrowing and plaque morphology, making it the preferred modality in complex or uncertain cases. The contrast-enhanced imaging of CTA enables precise differentiation between soft, mixed, and calcified plaques, a critical factor in assessing stroke risk and treatment planning**[12]**. In contrast, while DUS is still a widely used first-line imaging modality due to its non-invasive nature and lack of radiation exposure, its accuracy is influenced by operator ability and acoustic interference, particularly in patients with heavily calcified plaques**[13]**.

This study proved a significant correlation between DUS-derived hemodynamic parameters, such as peak systolic velocity (PSV) and end-diastolic velocity (EDV), and CTA-measured stenosis. However, discrepancies were seen in cases where heavily calcified plaques caused acoustic shadowing, leading to underestimation or overestimation of stenosis severity in DUS. Additionally, while DUS allows for real-time vascular assessment and flow dynamics evaluation, it lacks the spatial resolution and comprehensive vascular mapping provided by CTA. These limitations highlight the necessity of a multimodal approach in certain clinical scenarios, where discordant findings between DUS and CTA call for further evaluation with digital subtraction angiography (DSA) as the gold standard**[14]**.

An important advantage of CTA seen in this study was its time efficiency, as it provided rapid and detailed visualization of the carotid vasculature within minutes. This is particularly relevant in acute stroke settings, where immediate decision-making about thrombolysis or endovascular intervention is needed**[15]**. However, CTA has inherent drawbacks, including exposure to ionizing radiation and the need for intravenous contrast, which may pose risks in patients with renal insufficiency or contrast allergies. On the other hand, DUS, despite requiring a longer acquisition time and being subject to operator variability, is still a cost-effective, bedside-friendly imaging tool that can be repeated without safety concerns**[16]**.

The findings of this study are consistent with earlier research, reinforcing the role of CTA as the preferred modality in high-risk patients requiring definitive stenosis assessment. However, DUS continues to hold value as a first screening tool, especially in asymptomatic individuals or for routine post-intervention surveillance**[17]**. The combined use of both modalities, using the strengths of each, may perfect the diagnostic workflow and reduce the need for invasive angiography. Future advancements in imaging technology, such as artificial intelligence-assisted DUS and contrast-enhanced ultrasound, may further improve the accuracy of non-invasive carotid artery evaluation**[18]**.

This study's strengths include a well-defined patient cohort and the use of standardized imaging protocols, ensuring a reliable comparison of CTA and DUS. However, some limitations must be acknowledged. The operator dependency of DUS introduces variability in stenosis grading, and the retrospective nature of this study may introduce selection bias. Additionally, while the diagnostic accuracy of both modalities was assessed, long-term clinical outcomes such as stroke incidence were not analyzed, calling for further prospective research.

CONCLUSION

In summary, this study highlights the superior diagnostic accuracy of CT angiography over Doppler ultrasound in detecting carotid artery stenosis, particularly in cases of high-grade stenosis and complex vascular anatomy. While CTA provides detailed plaque characterization and rapid imaging, its use is limited by radiation exposure and contrast administration. DUS, despite its lower sensitivity in certain cases, is still a valuable first-line tool due to its accessibility, cost-effectiveness, and safety. The choice between these modalities should be guided by clinical context, patient-specific risk factors, and institutional availability. In cases where stenosis severity is still uncertain, a combined approach using both imaging techniques may provide best diagnostic accuracy. Future research should focus on enhancing non-invasive imaging modalities to reduce dependence on contrast-based angiography, ultimately improving stroke prevention strategies and patient outcomes.

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