Section: Radiodiagnosis

Original Research Article

THE HIDDEN RISK WITHIN: MORPHOLOGICAL AND HEMODYNAMIC EVALUATION OF CAROTID ATHEROSCLEROTIC PLAQUES USING DOPPLER ULTRASONOGRAPHY IN ACUTE ISCHEMIC STROKE

Swarna Laxmi[1], Rajul Rastogi[2], Aman Taneja[3]

[1]Senior Resident, Department of Radiodiagnosis, Dr. Ram Manohar Lohia Institute of Medical Sciences, (DR.RMLIMS), Lucknow, Uttar Pradesh, India
[2]Professor, Department of Radiodiagnosis, Teerthanker Mahaveer Medical college and Research Centre,(TMMC & RC) Moradabad, Uttar Pradesh, India
[3]Senior Resident, Department of Radiodiagnosis, Govind Ballabh Pant Hospital, (GB PANT) New Delhi, India

Received *: 05/05/2026*
Received in revised form *: 18/06/2026*
Accepted *: 01/07/2026*

Corresponding Author:
Dr. Swarna Laxmi,
Senior Resident, Department of Radiodiagnosis, Dr. Ram Manohar Lohia Institute of Medical Sciences, (DR.RMLIMS), Lucknow, Uttar Pradesh, India.
Email: drswarna1410@gmail.com

DOI: 10.70034/ijmedph.2026.3.455

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (3); 2891-2896

ABSTRACT

Background: The objective is to measure composite intima-media thickness of carotid artery. To determine percentage & the varying degree of luminal narrowing and carotid artery stenosis. To determine morphological feature of the various plaque components along with its hemodynamic changes on carotid Doppler ultrasonography.

Materials and Methods: This observational study included 54 patients with acute ischemic stroke evaluated over 18 months in a tertiary care center after institutional ethics approval and informed consent. Various types of carotid plaques (I-V) along with degree of stenosis and pre as well as post-stenotic segmental velocities were recorded in each patient. The observations were tabulated and analyzed using SPSS software to calculate the p-value.

Results: The study population was predominantly male and older than 60 years. The left internal carotid artery was slightly more frequently involved than the right. Type II plaques (predominantly sonolucent) were the most common. A significant association was observed between Type II and III plaques and increasing luminal stenosis. Pre-stenotic peak systolic velocity also showed a significant correlation with the degree of stenosis.

Conclusion: On the basis of comprehensive observations made in our study, the following conclusions can be drawn:
Acute ischemic stroke demonstrates a predilection for elderly males with predominant involvement of the left internal carotid artery. Sonolucent and heterogeneous plaques (Types II and III), indicative of lipid-rich and potentially vulnerable morphology, show significant association with higher grades of luminal stenosis and altered hemodynamics, particularly elevated pre-stenotic peak systolic velocities. Increased carotid intima–media thickness further reflects underlying atherosclerotic burden. Carotid Doppler ultrasonography enables comprehensive plaque characterization, facilitating identification of high-risk plaques beyond conventional stenosis-based assessment.

Keywords: Stroke, Ischemic, Carotid Stenosis, Ultrasonography Doppler, Atherosclerosis, Intima-Media Thickness.

INTRODUCTION

Stroke is the 4th leading cause of death in India.[1] Atherosclerosis of carotid artery is a substantial risk factor for occurrence of ischemic stroke, which is directly related to morphology of plaque, neovascularization within plaque and microembolization to brain. The bifurcation of carotid artery is the preferential location for plaque

formation related to local shearing forces on the wall leading to an impairment in endothelial function.[2]

The plaque formation in the wall of carotid artery causing luminal narrowing or stenosis which can be identified easily with by carotid doppler ultrasonography (CDU). Hence, CDU is a primary screening modality for evaluation of atherosclerosis in the extracranial branch of carotid artery as it is readily available, non-invasive & relatively inexpensive. This evaluation is crucial since the risk of stroke increases with increasing atherosclerotic stenosis leading to flow disturbances.[3] In addition, CDU can categorize plaque into organized and vulnerable necrotic plaque.

For decades, the risk stratification and imaging marker used globally for stroke is narrowing or stenosis of carotid artery. However, the stenosis secondary to the carotid artery plaque provides limited information related to actual risk of stroke. With recent advancements in diagnostic radiology, the role of USG has been recognized for detailed characterization of plaque morphology and additional risk stratification.[4]

The carotid plaque load in patients with recurrent episodes of ischemic stroke is usually very high, thus needing continuous & regular monitoring of the plaque progression for secondary stroke predictability. Carotid USG well demonstrates the main hallmarks of plaque vulnerability by characterization of its various pattern and with its ability to be able to differentiate the high risk from low risk plaques.[2,3]

Morphology of carotid plaque is linked with the pathology & genesis of ischemic stroke with specific plaque features serving as key predictors of cerebrovascular events including stroke. It helps in evaluating patients with higher risk of ischemic stroke so that apt measures that are preventive can be taken to mitigate this risk. Ongoing research attempt to distinctly clarify the interplay between morphology plaque, vascular biology, and vascular thrombosis needed for redefining risk stratification, risk management and optimizing clinical outcomes in carotid atherosclerosis.

Recently published studies in the medical literature suggest that different type of plaque morphology including Lipid rich necrotic core (LRNC), thin ruptured fibrous cap & ulceration (TRFC) and intraplaque hemorrhage (IPH).

The increase in the size of LRNC associated with ulceration and the rupture of fibrous cap over the plaque has been described as a leading cause of ischemic stroke.[4] The IPH represents advanced stage of atherosclerosis identified as a transition point from stable to unstable plaque, independent of the degree of stenosis, thus a target for screening.

The majority of previous studies focused mainly on the degree of stenosis and, secondarily, on plaque morphology. However, our study is primarily aimed at investigating the morphological characteristics of carotid plaque and evaluating the diagnostic value of CDU. Our goal is to provide insights into their respective roles in clinical practice.

MATERIALS AND METHODS

This observational study was conducted on 54 cases in the Department of Radiodiagnosis of our Tertiary Care Hospital over a period of 18 months following approval from the College Research Committee & Institute Ethics Committee using the following criteria and after obtaining written & informed consent.

Inclusion criteria

All stroke patients showing plaque on Carotid Doppler study.

Exclusion criteria

Non-cooperative patient & those with previous surgical interventions.

All the participants were examined in the supine position with pillow placed beneath the shoulders for proper visualization of carotid arteries during the examination on SIEMENS ACUSON S2000 & S3000 USG scanner using 9L4 (4-9MHz) and 14L5 (5-14MHz) linear array probes. All the findings found was then recorded in the predesigned patient proforma followed by data entry into the MS excel spreadsheet. The data found was then analyzed by using SPSS software and ANOVA test.. The findings evaluated included:

- Composite intima medial thickness of carotid artery.
- Percentage and degree of luminal narrowing and carotid artery stenosis.
- Morphological feature of plaque components along with its hemodynamic changes on carotid Doppler.
- Angle corrected velocities obtained bilaterally at various levels and the final Carotid doppler report was prepared.[5]

The various types of plaques assessed on CDU were grouped into Type 1 (uniformly sonolucent), Type 2 (predominantly sonolucent), Type 3 (predominantly echogenic), Type 4 (uniformly echogenic) & Type 5 (unclassified due to calcifications causing inadequate visualization of plaque).[6]

Carotid doppler ultrasonography findings:

VARIABLE	RIGHT	LEFT
Intima media thickness	in mm	in mm
Luminal stenosis (%)		
DOPPLER MEASUREMENT		
ICA-PSV (Pre stenotic)	in cm/sec	in cm/sec
ICA-PSV (At stenotic)	in cm/sec	in cm/sec
ICA-PSV (Post stenotic)	in cm/sec	in cm/sec

Carotid USG study for plaque components characterisation: Ultrasonography

	PRESENT	ABSENT
LRNC		
IPH		
ULCERATION		
CALCIFICATION		

Statistical Analysis: The statistical analysis was meticulously performed using descriptive statistics to express quantitative variables as mean ± standard deviation and qualitative variables as frequency and percentage. A p-value of <0.05 was considered significant.

Risks from the study: No risks are involved in this study.

Confidentiality: Any information related to the patient was not disclosed except for patient management purposes.

RESULTS

[Table 1] illustrates the age-wise distribution of the 54 cases in the present study, with the majority of cases being aged, over 60 years, signifying higher occurrence of ischemic stroke and carotid artery stenosis in elderly population. Out of the 54 cases included, 40 were males and 14 were females. The study exhibited a male predominance with a male-to-female ratio of 2.8:1 signifying higher occurrence of ischemic stroke & carotid artery stenosis in males.

The majority of patients had plaque on the left side, predominantly involving the left internal carotid artery (observed in approximately 39% of the assessed patients). [Table 1] also depicts the distribution and morphology of various types of plaques assessed on on color doppler ultrasonography. The majority of patients exhibited Type 2 plaque (predominantly sonolucent) on B-mode imaging. [Table 2] did not show any significant difference in cases based on age & sex.

Table 1: Distribution of cases according to demographic and clinical factors

Age Group	Frequency (n=54)	Percentage (%)
<40	3	5.6
41-50	14	25.9
51-60	11	20.4
>60	26	48.1
Gender		
Female	14	25.9
Male	40	74.1
Location of Plaque		
LEFT CCA	8	14.8
LEFT ICA	21	38.9
RIGHT CCA	9	16.7
RIGHT ICA	16	29.6
Type of Plaque		
Type 1	12	22.2
Type 2	23	42.6
Type 3	11	20.4
Type 4	4	7.4
Type 5	4	7.4

Table 2: Correlation of Age & Gender in Cases

Age Group	Gender		Total	p-value
	Female (n)	Male (n)		
<40	0	3	3	0.600
41-50	5	9	14	
51-60	3	8	11	
>60	6	20	26	
Total	14	40	54	

Table 3: IMT and doppler parameters in cases

Characteristic	Mean	SD
Age (years)	58.13	11.76
IMT (mm)	1.08	0.28
Pre-stenotic	56.40	26.74
AT stenotic	88.37	38.95
Post stenotic	44.39	17.84
Luminal stenosis	0.41	0.12

[Table 3] presents the IMT and Doppler parameters assessed among cases using ultrasound. Among patients with a history of stroke, the mean IMT was 1.08 with a standard deviation of 0.28. The peak systolic velocity measured at the site of stenosis exhibited a significantly higher value compared to

both pre- and post-stenotic values. Additionally, the mean luminal stenosis caused by plaques in the affected vessels among cases was approximately 41 percent.

Table 4: Relationship of Pre & Post-Stenotic PSV with Luminal Stenosis in Cases

Characteristic	Mean	SD	p-value	Correlation
Pre-Stenotic	56.40	26.74	0.001	0.427
Luminal Stenosis	41.28%	12.15%		
Post-Stenotic	44.39	17.84	0.287	0.148
Luminal Stenosis	41.28%	12.15%		

Significant difference (p-value=0.001) in the pre-stenotic PSV with percentage of luminal stenosis and fair positive correlation is evident from the table. However, difference in post-stenotic PSV was insignificant with poor correlation with percentage of luminal stenosis. [Table 4]

Table 5: Relationship of Type of Plaque with Luminal Stenosis in Cases

Type of Plaque	Mean Luminal Stenosis	SD	p-value
Type 1	37.82%	9.01%	0.007
Type 2	46.88%	13.27%	
Type 3	41.02%	8.28%	
Type 4	35.40%	11.86%	
Type 5	26.10%	2.64%	

The maximum mean luminal stenosis was noted with Type 2 & 3 plaques followed by type 1 & 4 and least with type 5. This difference was significant with p-value of 0.007. [Table 5]

Table 6: Distribution of USG characteristics in cases

LRNC on USG	Frequency (n=54)	Percentage (%)
Present	47	87
Absent	7	13
IPH on USG		
Present	4	7.4
Absent	50	92.6
Ulceration on USG		
Present	10	18.5
Absent	44	81.5
Calcification on USG		
Present	18	33.3
Absent	36	66.7

Table 6 displays the frequency of lipid-rich necrotic core detection on ultrasound (USG) in cases. Out of 54 cases, a lipid-rich necrotic core was found in 47 patients on ultrasound (87%). An intraplaque hemorrhage (IPH) was seen in only 4 out of 54 cases in the present study. Among the total cases, 10 had the presence of ulceration on ultrasound and 18 showed the presence of calcification in the plaque on the USG modality.

DISCUSSION

Our study included 54 patients with ischemic stroke & carotid artery stenosis in the mean age of 58.13+11.76years and predominance of patients >60 years (48.1%). Males outnumbered females in our study group with M:F ratio of 2.8:1. However, there was no significant difference in our cases based on age & sex.

Majority of the patients (68.5%) had plaque in internal carotid artery, predominantly on the left side (38.9%) followed by common carotid artery (31.5%) with predominance of right side (16.7%).

Among the various types of plaques assessed on CDU, majority (42.6%) had Type 2 plaque (predominantly sonolucent) followed by Type 1 (uniformly sonolucent, 22.2%) & Type 3 (predominantly echogenic, 20.4%). Type 4 (uniformly echogenic) & Type 5 (unclassified due to calcifications causing inadequate visualization of plaque) were the least common (7.4% each).

The mean IMT in our study group was 1.08+0.28 with mean stenosis of 41+12%. The PSV was maximal at the site of stenosis (mean 88.37+38.95cm/sec), significantly higher than pre- (56.40+26.74cm/sec) and post-stenotic (44.39+17.84cm/sec) values. Significant difference and fair positive correlation were noted in the pre-stenotic PSV with percentage of luminal stenosis without such relationship between post-stenotic PSV & percentage of luminal stenosis.

The maximum mean luminal stenosis in our study was noted with Type 2 & 3 carotid plaques followed by type 1 & 4 and least with type 5 plaques. This difference was significant with p-value of 0.007.

Age and Gender Distribution: Our research participants had an average age of 58.13 years, with a standard deviation of 11.76 years, and there was a predominance of individuals over 60 years of age. This suggests a notably high prevalence of carotid plaque abnormalities in the elderly population. Spence et al,[7] (2002) emphasized that the

likelihood of carotid artery disease increases with age, particularly after the age of 60. Similarly, Jones et al,[1] (2022) documented a higher incidence of stroke in elderly populations in India, providing further support for the demographic trends observed in our study.

Gender distribution in our study revealed male dominance (74.1% males vs 25.9% female), which is synchronous with findings of Nagai et al,[8] (2002) and Jones et al. (2022),[1] who reported a higher incidence of carotid artery disease in males. This gender disparity is attributed to hormonal differences, lifestyle factors, and the protective effects of estrogen in premenopausal women.

Site and Type of Plaque: In our study, the left ICA was the most frequently affected artery (38.9%), followed by the right ICA (29.6%), right CCA (16.7%) and left CCA (14.8%). This distribution is indicative of the ICA susceptibility to atherosclerotic changes, which has a critical role in supplying blood to the brain.

In our study, Type 2 plaques were the most prevalent (42.6%) indicating a higher risk of ischemic events compared to other more stable plaques as noted by Nandalur et al 2005.[9] This categorization of high-risk plaques is considered crucial in determining appropriate management (medical versus therapeutic interventions).

LRNC and IPH: The presence of LRNC and IPH has been considered as a significant marker of plaque vulnerability and risk of stroke. In our study, LRNC was detected in 87.0% of patients on USG. The high sensitivity & specificity of USG in detecting LRNC corroborates with Gronholdt et al,[10] (2001) & Lee et al (2014).[3]

Ulceration and Calcification: Ulceration & calcification are markers of advanced atherosclerotic disease. In our study, USG detected ulceration in 18.5% of patients. The findings are similar to Nandalur et al. (2005).[9]

Calcification was identified in 33.3% of patients on USG. Calcified plaques are generally considered more stable, but the presence of calcification still pose significant risks particularly in severe stenosis as stated by Nandalur et al. (2005).[9]

To summarize, our study assessed the role of color doppler ultrasonography (CDU) in evaluating carotid plaque morphology in ischemic stroke patients. The findings from our study have provided valuable insights to the identification and characterization of various plaque components, such as lipid-rich necrotic core (LRNC), ulceration, intraplaque hemorrhage (IPH), and calcification using CDU.

The existing data indicates that ultrasonography (USG) serves as a valuable initial tool for evaluating carotid plaques in the characterization of high-risk features providing guidance for management decisions.

Clinical implications: The results of this study hold great importance for the clinical management of patients who have suffered from ischemic stroke. Accurately characterizing the morphology of plaque and identifying high-risk features such as LRNC and IPH are crucial for effectively assessing the risk and making informed decisions about treatment. The high sensitivity and specificity of USG make it an excellent initial screening tool for detecting LRNC. This information can be used by clinicians to tailor treatment strategies, including initiating more aggressive medical therapy or considering various surgical procedures for patients with high-risk plaques.

Additionally, the accurate detection of ulceration and calcification can inform decisions about the requirement for revascularization procedures. For patients with significant ulceration or calcification, close monitoring and targeted interventions can be beneficial in preventing stroke recurrence.

Acknowledgement: The authors would like to acknowledge the support of the Department of Radiodiagnosis at our institution for providing the necessary infrastructure and technical assistance for this study. We are grateful to the faculty and staff for their cooperation and guidance throughout the study period.

We sincerely thank all the patients who participated in this study for their cooperation and consent.

We also acknowledge the contribution of the biostatistics department for their assistance in data analysis, and the Institutional Ethics Committee and College Research Committee for their review and approval of the study protocol.

CONCLUSION

The present study demonstrates that carotid atherosclerotic disease in patients with ischemic stroke predominantly affects elderly males, with the internal carotid artery—particularly on the left side—being the most frequent site of involvement. Type 2 (predominantly sonolucent) plaques constituted the most common plaque morphology, followed by Type 1 and Type 3 plaques, while Type 4 and Type 5 plaques were relatively uncommon.

A significant association was observed between plaque morphology and the degree of luminal stenosis, with Type 2 and Type 3 plaques exhibiting the highest grades of stenosis. Increased carotid intima–media thickness was a consistent finding among patients with ischemic stroke, underscoring its value as a marker of atherosclerotic burden.

Peak systolic velocity was significantly elevated at the site of stenosis compared with pre- and post-stenotic segments, and pre-stenotic PSV demonstrated a positive correlation with the severity of luminal narrowing.

Carotid Doppler ultrasonography proved to be a reliable and effective non-invasive modality for the assessment of carotid atherosclerosis, enabling detailed evaluation of plaque morphology, plaque surface characteristics, calcification, and hemodynamic significance of stenosis. Its ability to

simultaneously characterize plaque features and quantify stenosis highlights its important role in the risk stratification and management of patients with ischemic cerebrovascular disease.

REFERENCES

1. Jones SP, Baqai K, Clegg A, Georgiou R, Harris C, Holland EJ, Kalkonde Y, Lightbody C. Stroke in India: A systematic review of the incidence, prevalence, and case fatality. Int J Stroke. 2022;17(2):132-140.
2. Kassem M, Florea A, Mottaghy FM, van Oostenbrugge R, Kooi M. Magnetic resonance imaging of carotid plaques: current status and clinical perspectives. Ann Transl Med. 2020 8(19):1266.
3. Lee W. General principles of carotid Doppler ultrasonography. Ultrasonography. 2014;33(1):11-17.
4. Porambo ME, DeMarco JK. MR imaging of vulnerable carotid plaque. Cardiovasc Diagn Ther. 2020;10(4):1019-1031.
5. Che F, Mi D, Wang A, Ju Y, Sui B, Geng X, et al. Extracranial carotid plaque hemorrhage predicts ipsilateral stroke recurrence in patients with carotid atherosclerosis – a study based on high-resolution vessel wall imaging MRI. BMC Neurol. 2022 Jun 28;22:237.
6. Geroulakos G, Ramaswami G, Nicolaides A, James K, Labropoulos N, Belcaro G, et al. Characterization of symptomatic and asymptomatic carotid plaques using high-resolution real-time ultrasonography. Br J Surg. 1993 Oct;80(10):1274–7.
7. Spence JD, Eliasziw M, DiCicco M, Hackam DG, Galil R, Lohmann T. Carotid plaque area: a tool for targeting and evaluating vascular preventive therapy. Stroke. 2002 Dec;33(12):2916–22.
8. Nagai Y, Kitagawa K, Yamagami H, Kondo K, Hougaku H, Hori M, et al. Carotid artery intima-media thickness and plaque score for the risk assessment of stroke subtypes. Ultrasound in Medicine & Biology. 2002 Oct 1;28(10):1239–43.
9. Nandalur KR, Baskurt E, Hagspiel KD, Phillips CD, Kramer CM. Calcified Carotid Atherosclerotic Plaque Is Associated Less with Ischemic Symptoms Than Is Noncalcified Plaque on MDCT. American Journal of Roentgenology. 2005 Jan;184(1):295–8.
10. Grønholdt MLM, Nordestgaard BG, Schroeder TV, Vorstrup S, Sillesen H. Ultrasonic Echolucent Carotid Plaques Predict Future Strokes. Circulation [Internet]. 2001 Jul 3 [cited 2025 Mar 10]; Available from: https://www.ahajournals.org/doi/10.1161/hc2601.091704.