

Color Doppler Evaluation of Extra Cranial Carotid Artery in Patients Presenting with Acute Ischemic Stroke and Correlation with Various Risk Factors

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Abstract:

Background: Stroke is defined as an abrupt onset of neurologic deficit due to vascular cause. It is one of the leading causes of mortality and morbidity all over the world making early diagnosis and treatment inevitable.

Objective: The present study highlights the importance of Doppler sonography in acute ischemic stroke patients through surveillance of atherosclerosis.

Materials and methods: This cross-sectional study was conducted in the Department of Radiology and Imaging, Mymensingh Medical College Hospital, from September 2016 to February 2018. It included 52 stroke patients referred for CT scan evaluation. Patients meeting the inclusion criteria were selected, while those meeting exclusion criteria were omitted.

Results: The mean age was 62.48 ± 8.74 years (range: 35–85), with a male-to-female ratio of 1.4:1. Among 34 hypertensive patients, 72.5% had stenosis, and 70% had atherosclerotic changes. Family history was positive in 16 (30.8%) cases, with 7 (20%) showing atherosclerosis. Diabetes was present in 11 (21.1%) patients, with 7 (17.5%) exhibiting stenotic changes. Increased CIMT was observed in 30 (57.7%) patients, with bilateral involvement in 16 (53.3%) cases. Arterial plaques were found in 24 (46.2%) patients, most commonly at the bifurcation (54.2%). Echogenic plaques (58.3%) were predominant. Stenosis was present in 40 (76.9%) patients, affecting the right side in 17 (42.5%), left in 11 (27.5%), and bilaterally in 12 (30%). Most cases (85%) had <50% stenosis, while 12.5% had >50% stenosis, and 2.5% had near occlusion. Atherosclerosis was detected in 35 (67.3%) patients, with 31 also having stenosis (statistically significant). Hypertension and hyperlipidemia showed significant associations with stenosis ($p < 0.05$).

Conclusion: Anterior circulation stroke was more common, with the MCA territory being the most affected. Hypertension and diabetes were the most prevalent risk factors, while hypertension and hyperlipidemia correlated most with stenosis. Carotid bifurcation was the most common plaque site, with echogenic plaques being predominant.

Keywords: Color Doppler, extra cranial, Carotid Artery, acute ischemic stroke, risk factors

1. INTRODUCTION

Stroke is acute onset of focal neurological deficit lasting over 24 hours with no apparent cause other than vascular origin. The cut-off of 24 hours in the definition excludes transient ischemic attacks.¹ Stroke is classified according to its aetiology into either ischemic stroke (85%) or haemorrhagic stroke. Strokes are thromboembolic in nature in about 80% of cases and the embolus comes from the carotid plaque.²

Carotid standard angiography is a gold standard for evaluation of severity of carotid disease, yet there are limitations in the form of invasive technique and cost effectiveness, which limit its use. It carries a risk of contrast medium to patients along with certain morbidity.

Most common imaging investigation performed worldwide for the help of diagnosis of carotid disease is Doppler USG. This modality is slowly becoming the sole exam done prior to surgery. The panelists estimated that up to 80% of patients in the US undergo carotid endarterectomy following a USG exam as the sole preoperative imaging study. Thus, it is imperative that data supplied by the USG exam be reliable and reproducible.³

Carotid sonography is unique among vascular imaging examinations in the assessment of plaque position and consistency. Plaque features detected by carotid Doppler may be useful in selecting medical and surgical therapy.⁴ Carotid ultrasonography plaques were described in many different ways in the previous conducted research studies. In this study, we took into consideration the morphology, position of the plaque, as well as its characteristics. Plaque characteristics such as echogenic, hypoechoic or calcified and ulcerated or smooth or any intraplaque haemorrhage were noted. Intraplaque haemorrhages inside the carotid plaques lead to frank ulceration and significant luminal narrowing by quick progression⁵ the most common site for plaque formation is the carotid bifurcation.⁶ This is due to the fact that here there is sudden and sudden alteration in the speed and direction of blood in the bulb region leading to increase in stress faced by the arterial walls and thus more susceptible to getting damaged.⁷

Correlation of carotid artery stenosis with other risk factors such as diabetes mellitus, hypertension, hyperlipidemia, smoking and age was confirmed by thorough clinical history,

laboratory investigations and clinical examination of the patients.⁸

Atherosclerosis in hypertension is due to repeated endothelium trauma and ultimately leads to plaque formation as well as growth of plaque. Diabetes mellitus is a proven significant risk factor. Plasminogen activator antigen and plasminogen activator inhibitor-I have been shown to have significant correlation with ischemic stroke in diabetic patients.⁹

Progressive atherosclerotic disease results into pathological intimal thickening, fibrous cap atheroma and plaque formation. Early detection helps to control the disease in patients who are at risk.¹⁰ Duplex sonography combining high-resolution imaging and Doppler spectrum analysis has proved to be a popular, noninvasive, accurate, and cost-effective means of detecting and assessing carotid disease.

The present study highlights the importance of Doppler sonography in stroke patients through surveillance of various risk factors that predisposes a person to cerebral ischemia. In future routine screening of high-risk patients is necessary to prevent the occurrence of stroke.

2. MATERIALS AND METHODS

This was cross-sectional study carried out in the Department of Radiology and Imaging, Mymensingh Medical College Hospital, Mymensingh from September, 2016 to February, 2018 (18 months). The study was included about 52 patients of either sex with stroke, are referred to the department of Radiology and Imaging, for CT scan evaluation. All the admitted patients with stroke at the department of medicine & neuromedicine in Mymensingh Medical College, Hospital. Among them those was selected for this study who would fulfill the inclusion criteria and some were excluded from this study if they followed the exclusion criteria. After taking consent including parents, detail history was taken. History about any other complication also was taken and noted in questionnaire. Detailed clinical examination was carried out. Then CT scan was performed in Radiology & Imaging Department. If CT scan feature shows ischemia or infarction then color Doppler of carotid arteries was done. Carotid arteries were examined with patient in the supine position. Neck exposure was enhanced by tilting and rotating the head away from the side being examined, and ipsilateral shoulder being dropped as far as possible. The examiner was seated at the

right side of the patient. The posterolateral and far posterolateral transducer positions were used to examine the carotid arteries in long axis (longitudinal). Short axis (transverse) views of the carotid arteries were obtained from an anterior, lateral or posterolateral approach. All the examinations were performed by the same operator with a Doppler angle of 60°. On gray scale, presence or absence of plaque, location of plaque and plaque characteristics such as echo pattern, calcification, any ulceration or intra-plaque haemorrhage were evaluated. On Doppler study, PSV of CCA and ICA were evaluated. Criteria used for measuring percentage of stenosis in our study: ICA/CCA PSV ratios.

3. RESULTS

The study included 52 patients, with a mean age of 62.48 ± 8.74 years (range: 35–85 years) (Table 1). The majority of patients (55.8%) were in the 56–65 age group, followed by 21.2% in the 66–75 age group. Males constituted 59.6% of the study population, while females accounted for 40.4% (Table 1).

Among the study patients, hypertension was the most prevalent risk factor (65.4%), followed by hyperlipidemia (32.7%) and smoking (32.7%). Diabetes mellitus was present in 21.7%, and 30.8% had a family history of cardiovascular diseases (Table 2). Ultrasonographic assessment of intima-media thickness (IMT) revealed an

increase in 53.3% of patients in both common carotid arteries (CCA), 30% in the right common carotid artery (RCCA), and 16.7% in the left common carotid artery (LCCA) (Table 3). Plaques were identified in 24 patients with the most common location being the carotid bifurcation (54.2%), followed by the internal carotid artery (ICA) (29.1%) and the CCA (16.7%) (Table 4). Atherosclerosis was present in 35 patients with 40% having involvement in the RCCA, 22.8% in the LCCA, and 37.2% in both CCA. Carotid stenosis was found in 40 patients, predominantly in the right ICA (42.5%), followed by the left ICA (27.5%) and both ICAs (30%) (Table 5). Among the 40 patients with stenosis 85% had stenosis of less than 50%, while 12.5% had stenosis greater than 50%, and 2.5% had near-total occlusion (Table 6). Hyperlipidemia was significantly associated with carotid stenosis ($p < 0.05$), while diabetes mellitus, hypertension, smoking, and family history did not show statistically significant associations (Table 7). Hyperlipidemia was significantly associated with atherosclerosis ($p < 0.05$), whereas diabetes mellitus, hypertension, smoking, and family history showed no significant association (Table 8). Atherosclerosis and stenosis were significantly associated ($p < 0.05$), indicating that patients with atherosclerosis are more likely to develop carotid stenosis (Table 9).

Table 1. Distribution of study patients age and sex (n=52)

Characteristics	Number of the patients	Percentage (%)
Age in years		
35-45	1	1.9
46-55	8	17.3
56-65	29	55.8
66-75	11	21.2
76-85	2	3.8
Total	52	100.00
Mean±SD	62.48±8.74	
Range	35-85	
Sex		
Male	31	59.6
Female	21	40.4
Total	52	100.0

Table 2. Distribution of study patient by risk factors (n=52)

Clinical variables	Number of patient	Percentage (%)
Hypertension	34	65.4
Diabetes mellitus	11	21.7
Hyperlipidemia	17	32.7
Family history	16	30.8
Smoking	17	32.7

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Table 3. Measurement of intima-media thickness of the study patient (n=52)

USG	Number of patient	Percentage (%)
Increased in RCCA	9	30
Increased in LCCA	5	16.7
Increased in both CCA	16	53.3
Absent	22	73.3

Table 4. Distribution of plaque according to location (n=24)

Arterial plaque	Number of patient	Percentage (%)
Present in CCA	4	16.7
Present in Bifurcation	13	54.2
Present in ICA	7	29.1

Table 5. Measurement of atherosclerosis (n=35) and carotid stenosis (n=40)

	Number of patient	Percentage (%)
Atherosclerosis		
Present in RCCA	14	40.0
Present in LCCA	8	22.8
Present in both CCA	13	37.2
Stenosis		
Present in RICA	17	42.5
Present in LICA	11	27.5
Present in both ICA	12	30.0

Table 6. Distribution of study patient according to percentage of stenosis (n=40)

Stenosis	Number of patient	Percentage (%)
<50%	34	85.0
>50%	5	12.5
Near occlusion	1	2.5

Table 7. Relation between risk factors and carotid stenosis (n=40)

	Stenosis		P value
	Present	Absent	
DM			
Present	7	4	>0.05*ns
Absent	33	8	
Hyperlipidemia			
Present	16	1	<0.05*s
Absent	24	11	
Family history			
Present	10	6	>0.05*ns
Absent	30	6	
Smoking			
Present	13	4	>0.05*ns
Absent	27	8	
Hypertension			
Present	29	5	<0.05*ns
Absent	11	7	

Table 8. Relation between risk factors and atherosclerosis (n=35)

	Stenosis		P value
	Present	Absent	
DM			
Present	24	7	>0.05*ns
Absent	11	10	
Hyperlipidemia			
Present	16	1	<0.05*s
Absent	19	16	

Family history			
Present	7	9	<0.05*ns
Absent	28	7	
Smoking			
Present	12	5	>0.05*ns
Absent	23	12	
Hypertension			
Present	28	6	<0.05*ns
Absent	7	11	

Table 9. Relation between atherosclerosis and stenosis

Atherosclerosis	Stenosis		P value
	Present	Absent	
Present	31	4	<0.05*ns
Absent	9	8	

4. DISCUSSION

Stroke or cerebrovascular disease is an important formidable health problem globally. Approximately one- third of acute cases have a fatal outcome. Doppler sonography is a safe, non-invasive, accurate and less time consuming method of diagnosing carotid stenosis. The present study highlights the importance of Doppler sonography in stroke patients through surveillance of various risk factors that predisposes a person to cerebral ischemia. In future routine screening of high risk patients is necessary to prevent the occurrence of stroke.

A total of 52 patients in the department of Radiology & Imaging of Mymensingh Medical college Hospital (MMCH), Mymensingh with symptomology of stroke referred from outpatient department or hospital indoor patients during September, 2016 to February, 2018(18 months) for the purpose of CT scan of brain and diagnosed as infarction were enrolled in this study. The present study findings were discussed and compared with previously published relevant studies.

In the present study, most stroke patients (55.8%) belonged to the 56–65 years age group, with a mean age of 62.48 ± 8.74 years. Haq et al.⁸ found a similar trend, with most patients in the 51–60 years group (34%), followed by 61–70 years (28%). Shaha et al. (2016) also reported the highest incidence in the 51–60 and 61–70 years groups (34% each), followed by 41–50 years (18%), >80 years (8%), and 71–80 years (6%). Fernandes et al.⁵ observed the highest incidence in the 60–69 age group (32%), followed by 70–79 years (26%).

Male predominance was noted in the present study (59.6%), consistent with findings by Shaha

et al.¹¹ (84% males), Lernolo et al.¹² (2.5% females), and Haq et al.⁸ (60% males).

Laterality distribution was equal on right and left sides (19 each), with 14 bilateral cases. In contrast, Baidya et al.³ found left-sided lesions in 52% of patients. Anterior circulation strokes were more common in our study, consistent with Haq et al.⁸.

Hypertension was the most prevalent risk factor (65.4%) and showed strong correlation with atherosclerosis and stenosis. Mean systolic BP was 142.41 mmHg in males and 148.57 mmHg in females, similar to Sethi et al.¹³ (139.3 mmHg in males, 142.8 mmHg in females). Dhamija et al.¹⁴ also emphasized hypertension as a key risk factor.

Hyperlipidemia was found in 32.7% and, along with hypertension, showed strong correlation with atherosclerosis—consistent with Garg et al.¹⁵.

Diabetes mellitus was seen in 21.2% of patients; 7 had stenosis. Unlike our findings, Sethi et al.¹³ reported 8 of 16 diabetic patients with <40% stenosis, and 3 with >40% or occlusion.

Family history was positive in 30.8%, aligning with Shaha et al.¹¹ (38%) and Reddy et al.¹⁶ (38%).

A CIMT cutoff of 0.09 cm was used, in line with Polak et al.¹⁷ and Jadhav et al.¹⁸ who identified >0.8 mm as early atherosclerotic change.

Plaques were most common at the bifurcation (54.16%), followed by ICA (29.16%) and CCA (16.66%). This is consistent with Sethi et al. (2004), Rajagopal et al.¹⁹, and Garg et al.¹⁵, all identifying bifurcation as the most commonly involved site due to flow disturbances.

Plaque characteristics such as echogenicity, calcification, ulceration, and intraplaque hemorrhage were evaluated. Most plaques in the present study were echogenic and smooth, with no ulceration or hemorrhage. This is consistent with Haq et al.⁸ who found echogenic plaques on the right side in 55.2% and left side in 55% of cases. Pasupuleti et al.²⁰ also found similar results with moderate echogenic plaques being most common.

In this study, 35 patients had atherosclerotic changes, of which 31 had stenosis—a statistically significant relation. Similar association was shown by Howard et al.²¹ across all ages. Regarding stenosis severity, 34 (85%) had <50%, 5 (12.5%) had >50%, and 1 (2.5%) had near occlusion. This aligns with Garg et al.¹⁵ and O'Leary et al.²² who found mild stenosis was most prevalent and severe stenosis less common.

Robinson et al.²³ and Erickson et al.²⁴ describe features of complete occlusion, including absent pulsation, echogenic filling, reduced vessel size, and no Doppler signals. The near occlusion case in our study met these criteria.

Doppler findings showed that an ICA/CCA PSV ratio <1.8 indicates <50% stenosis; >1.8 suggests >50%; >2.6 implies >60%; and >3.7 indicates >80% stenosis. Grant et al.⁹ noted ratios between 2.0–4.0 for 50–69% stenosis and >4.0 for >70%. NASCET found endarterectomy beneficial for stenosis ≥60%. In our study, PSV ratio >1 indicated <50% stenosis, >2 for 50–69%, and >3 for >70%. Haq et al.⁸ also used similar criteria, finding 40% of patients with <50%, 14% with 50–69%, 6% ≥70%, and 18% with significant stenosis >60%. In our findings, 34 (65.38%) had <50%, 3 (5.76%) had 50–69%, 2 (3.84%) had >70%, and 1 had near occlusion.

These findings confirm the utility of carotid sonography in identifying plaque morphology and stenosis in high-risk individuals. Most patients were aged 55–65, indicating that screening should be considered in individuals above 50 with risk factors.

Study limitations include its hospital-based nature at a government institution, possibly underrepresenting higher socioeconomic groups. Short duration, small sample size, and operator dependency of Doppler ultrasonography also limit generalizability. Hence, results may not reflect the broader population.

5. CONCLUSION

In the present study, anterior circulation stroke was more common than posterior circulation stroke with MCA territory being the most prevalent site of ischemic stroke. Hypertension and diabetes were most prevalent risk factors for stroke. Hypertension and hyperlipidemia showed maximum positive correlation with stenosis. Most common site of plaque was carotid bifurcation. Echogenic plaques were most commonly noted. Doppler sonography is a safe, non-invasive, accurate and less time consuming method of diagnosing carotid stenosis. The present study highlights the importance of Doppler sonography in stroke patients through surveillance of various risk factors that predisposes a person to cerebral ischemia. In future routine screening of high risk patients is necessary to prevent the occurrence of stroke.

REFERENCES

- [1] Smith WS, English JD and Johnston SC. Cerebrovascular diseases. Longo DL, Fauci AS, Kasper DL, Hauser DL, Jameson JL, Loscalzo J. Harrison's Principles of Internal Medicine. 19th ed., New York, McGraw Hill publication, 2012;3271-3291.
- [2] Donnan GA, Fisher M, Macleod M, Davis SM. Stroke. The Lancet 2008;371(9624):1612-1623.
- [3] Baidya OP. Acute ischemic stroke in young adults—a hospital based study in North India. Steroids 2015;6:2.
- [4] Park JB, Charbonneau F and Schiffrin EL. Correlation of endothelial function in large and small arteries in human essential hypertension. Journal of hypertension 2001;19(3):415-420.
- [5] Fernandes M, Keerthiraj B, Mahale AR, Kumar, A and Dudekula A. Evaluation of carotid arteries in stroke patients using color Doppler sonography: A prospective study conducted in a tertiary care hospital in South India. International Journal of Applied and Basic Medical Research 2016;6(1):3.
- [6] Petrovic S, Petrovic D, Rancic Z, Zivkovic M, Bojanovi, A and Budevac D. The significance of color doppler sonography in selection of patients for carotid endarterectomy. Acta Facultatis Medicae Naissensis 2006;23(1):31-38.
- [7] Lenzi GL and Vicenzini E. The ruler is dead: an analysis of carotid plaque motion. Cerebrovascular Diseases 2007;23(2-3):121-125.
- [8] Haq S, Mathur M, Singh J, Kaur N, Sibbia RS and Badhan R. Colour Doppler evaluation of extracranial carotid artery in patients presenting with acute ischemic stroke and

- correlation with various risk factors. Journal of clinical and diagnostic research: JCDR 2017;11(3): TC01-TC05.
- [9] Grant EG, Benson CB, Moneta GL, Alexandrov AV, Baker JD, Bluth EI, Carroll BA, Eliasziw M. Carotid artery stenosis: gray-scale and Doppler US diagnosis-Society of Radiologists in Ultrasound Consensus Conference. Radiology, 2003;229(2):340-346.
 - [10] Touboul PJ, Hennerici MG, Meairs S, Adams H, Amarenco P, Desvarieux M. Mannheim intima-media thickness consensus. Cerebrovascular diseases 2004; 18(4):346-349.
 - [11] Shaha P, RajV, Sahoo K. Evaluation of Carotid Vessels and Vertebral Artery in Stroke Patients with Color Doppler Ultrasound and MR Angiography. International journal of science and research. 2016; 5 (Issue 4):1136-1139.
 - [12] Lemolo F, Martiniuk A, Steinman DA and Spence JD. Sex differences in carotid plaque and stenosis. Stroke 2004; 35(2):477-481.
 - [13] Sethi SK, Solanki RS and Gupta H Color and duplex doppler imaging evaluation of extracranial carotid artery in patients presenting with transient ischaemic attack and stroke: a clinical and radiological correlation. Indian Journal of Radiology and Imaging 2005; 15(1):91-96.
 - [14] Dhamija RK and Dhamija SB. Prevalence of stroke in rural community--an overview of Indian experience. The Journal of the Association of Physicians of India 1998; 46(4):351-354.
 - [15] Garg KaShiKaR SV and PhataK S. Colour doppler evaluation or extracranial carotid arteries: a clinical and radiological correlation. Journal of clinical and diagnostic research: JCDR 2016; 10(1), TC06-TC09.
 - [16] Reddy A, Balla S, Krishnappa N, Bopaiah H, Suresh V and Gowda M. Comparative study of extracranial carotid and vertebral artery doppler with contrast enhanced MR angiography in patients with stroke. Journal of Evolution of Medical and Dental Sciences 2016;5(3):189-196.
 - [17] Polak JF, Pencina MJ, Pencina KM, O'donnell CJ, Wolf PA and D'Agostino Sr, RB. Carotid-wall intima-media thickness and cardiovascular events. New England. Journal of Medicine, 2011;365(3):213-221.
 - [18] Jadhav UM and Kadam NN. Carotid intima-media thickness as an independent predictor of coronary artery disease. Indian Heart Journal 2001; 53(4):458- 462.
 - [19] Rajagopal KV, Lakhkar BN, Banavali S and Singh NK. Pictorial essay: Color duplex evaluation of carotid occlusive lesions. Indian Journal of Radiology and Imaging 2000; 10(4):221.
 - [20] Pasupuleti BR, Narra RK, Kamraju SK, Jukuri NR and Sushmitha P. Color Doppler evaluation of carotid vessels in patients with stroke. International Journal of Medical Science Research and Practice 2015;2(1):12-15.
 - [21] Howard G, Manolio TA, Burke GL, Wolfson SK and O' Leary DH. Does the association of risk factors and atherosclerosis change with age? An analysis of the combined ARIC and CHS cohorts. Stroke 1997;28(9):1693-1701.
 - [22] O'leary DH, Polak JF, Kronmal RA, Kittner SJ, Bond MG, Wolfson Jr, SK.. Distribution and correlates of sonographically detected carotid artery disease in the Cardiovascular Health Study. The CHS Collaborative Research Group. Stroke, 1992;23(12):1752-1760.
 - [23] Robinson ML, Sacks D, Perlmutter GS and Marinelli DL. Diagnostic criteria for carotid duplex sonography. American Journal of Roentgenology 1988; 151(5):1045-1049.
 - [24] Erickson SJ, Mewissen MW, Foley WD, Lawson TL, Middleton WD, Quiroz FA. Stenosis of the internal carotid artery: assessment using color Doppler Imaging compared with angiography. American Journal of Roentgenology 1989; 152(6), pp.1299-1305.

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