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Original Research Article

Role of Ultrasonography in Carotid Doppler Study in Hypertensive Patients - Cross Sectional Observational Study in a Tertiary Care Centre

Dr. Rohan Dilip Birhade[1]*, Dr. Sunil S Patil[2], Dr. Shephali S Pawar[3]

[1]Junior Resident, Department of Radiodiagnosis, B. J. Government Medical College & Sassoon General Hospital, Pune, (MH) India
[2]Professor, Department of Radiodiagnosis, B. J. Government Medical College & Sassoon General Hospital, Pune, (MH) India
[3]Professor and Head of Department, Department of Radiodiagnosis, B. J. Government Medical College & Sassoon General Hospital, Pune, (MH) India

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Abstract: ***Background*:** Hypertension is an important risk factor for carotid atherosclerotic disease. Ultrasonography with Doppler provides non-invasive assessment of carotid arterial wall changes, plaque characteristics and blood-flow parameters. This study evaluated carotid artery changes in hypertensive patients using ultrasonography and Doppler. ***Methods*:** This cross-sectional observational study included 104 hypertensive patients. Bilateral carotid arteries were examined using grayscale, colour and spectral Doppler ultrasonography. Common carotid artery intima–media thickness (CCA-IMT), peak systolic velocity (PSV), end-diastolic velocity (EDV), resistive index (RI), plaque presence and morphology, and degree of stenosis were assessed. Associations with demographic and clinical characteristics were analysed. Receiver operating characteristic analysis was performed to assess the diagnostic performance of Doppler parameters. ***Results*:** The mean age was 52.66 ± 15.05 years, and 56.7% were females. Carotid plaques were detected in 49 patients (47.1%). Plaque presence was significantly associated with age (p=0.048), but not with gender, hypertension stage or duration. Hyperechoic and hypoechoic plaques were the commonest patterns (32.7% each). Plaque morphology was significantly associated with age (p=0.017), gender (p=0.034) and hypertension stage (p=0.003). Mild stenosis was observed in 73.5% and moderate stenosis in 26.5% of plaque-positive patients; no severe stenosis or occlusion was identified. CCA-IMT, CCA EDV and ICA PSV differed significantly across plaque morphologies. CCA PSV had the highest area under the curve (AUC) for plaque detection (0.632). For moderate stenosis, CCA PSV and ICA PSV showed AUCs of 0.736 and 0.714, respectively. ***Conclusion*:** Carotid ultrasonography and Doppler demonstrated a considerable prevalence of carotid plaques in hypertensive patients. Combined assessment of arterial wall thickness, plaque morphology and Doppler velocities may help characterise carotid atherosclerotic changes in this selected tertiary-care hospital study population.

Keywords: Carotid Doppler Ultrasonography.

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INTRODUCTION

Hypertension is a major modifiable risk factor for cardiovascular and cerebrovascular diseases. Persistent elevation of blood pressure produces structural and functional changes in the arterial system and contributes to hypertension-mediated organ damage. The 2023 European Society of Hypertension guidelines recognise carotid ultrasonography as an imaging modality that can be used to assess carotid intima–media thickness, atherosclerotic plaque and stenosis as part of the evaluation of vascular organ damage [1, 2].

Atherosclerosis is a chronic inflammatory process involving endothelial dysfunction, lipid accumulation and progressive remodelling of the arterial wall. Hypertension contributes to this process by increasing mechanical stress on the vascular endothelium and promoting vascular injury [3, 4]. The carotid arteries are particularly suitable for non-invasive assessment

***Corresponding Author:** Dr. Rohan Dilip Birhade
Junior Resident, Department of Radiodiagnosis, B. J. Government Medical College & Sassoon General Hospital, Pune, (MH) India

because of their superficial location and accessibility to high-resolution ultrasonography. B-mode imaging permits evaluation of the arterial wall, measurement of carotid intima–media thickness (CIMT), and identification of focal atherosclerotic plaques [3, 4].

CIMT represents the combined thickness of the intimal and medial layers of the arterial wall. Its measurement by ultrasound provides information about vascular wall changes associated with cerebrovascular risk factors.The Mannheim consensus recommends standardised acquisition and interpretation of CIMT measurements and distinguishes diffuse intima–media thickening from focal atherosclerotic plaque. A plaque is characterised by focal wall thickening that encroaches into the arterial lumen and meets specified thickness criteria [5. 6].

Carotid plaque assessment is clinically relevant because plaque provides evidence of established atherosclerotic disease. In a meta-analysis, Inaba and colleagues reported that carotid plaque assessment had better accuracy than CIMT alone for predicting future cerebrovascular events [7]. Similarly, the study by Polak and colleagues demonstrated the association of carotid wall measurements and plaque with subsequent cerebrovascular events [8]. These findings support the assessment of both arterial wall thickness and plaque rather than relying on a single ultrasound parameter.

Duplex carotid ultrasonography combines grayscale imaging with colour and spectral Doppler assessment. It enables evaluation of arterial morphology and haemodynamic characteristics, including peak systolic velocity (PSV), end-diastolic velocity (EDV) and resistive index (RI). The RI is calculated from the difference between PSV and EDV divided by PSV and provides an additional measure of arterial haemodynamic. Frauchiger and colleagues investigated carotid resistive indices in relation to CIMT as sonographic markers of atherosclerosis [9].

Carotid Doppler is also used to assess the degree of luminal narrowing. The Society of Radiologists in Ultrasound consensus recommends the combined use of grayscale, colour Doppler and spectral Doppler findings for evaluating internal carotid artery stenosis. ICA peak systolic velocity, in conjunction with visible plaque and other Doppler parameters, is used to classify stenosis severity [10].

In hypertensive patients, assessment of CIMT, plaque morphology, Doppler flow parameters and stenosis may provide a comprehensive description of carotid vascular changes. However, these parameters represent different aspects of arterial structure and haemodynamic and should be interpreted together. The present study was therefore undertaken to evaluate carotid artery changes in hypertensive patients using ultrasonography and Doppler, with particular emphasis on CIMT, plaque prevalence and morphology, Doppler indices, and the degree of carotid artery stenosis.

METHODOLOGY

A cross-sectional observational study was conducted in the Department of Radiodiagnosis, B. J. Government Medical College and Sassoon General Hospital, a tertiary care centre. A total of 104 diagnosed hypertensive patients aged above 18 years, attending the outpatient department or admitted to the inpatient department and referred for carotid Doppler evaluation, were enrolled using convenience sampling. Both male and female patients willing to provide written informed consent were included. Patients below 18 years of age, those with previously diagnosed carotid artery disease, previous cerebrovascular accident, renal disease, or unwillingness to participate were excluded. After obtaining Institutional Ethics Committee approval and written informed consent, demographic and clinical details were recorded using a structured proforma. Bilateral carotid Doppler ultrasonography was performed using a Mindray DC-60 Exp ultrasound system with a 7–12 MHz linear array probe. CIMT was measured in the distal 1 cm of the common carotid artery, approximately 1 cm proximal to the bifurcation. Plaques were documented for presence, location, size and echogenicity. Colour and spectral Doppler were used to assess luminal narrowing, PSV, EDV and RI. Data were analysed using SPSS version 26.0. Appropriate tests, including chi-square, Fisher's exact, independent t-test, Mann–Whitney U, ANOVA and Kruskal–Wallis tests, were applied. A p-value below 0.05 was considered statistically significant.

RESULT

Table 1: Demographic and clinical characteristics of study participants (N=104)

Characteristics	Frequency (n)	Percentage (%)
Age group (years)		
18–30	12	11.5
31–45	22	21.2
46–60	34	32.7
61–75	36	34.6
Gender		
Male	45	43.3
Female	59	56.7

Stage of hypertension		
Stage I	5	4.8
Stage II	99	95.2
Duration of hypertension		
≤5 years	27	26.0
6–10 years	27	26.0
>10 years	50	48.1

Clinical parameters	**Mean ± SD**	**Median (IQR)**
Age (years)	52.66 ± 15.05	53.50 (38.00–67.00)
Systolic blood pressure (mmHg)	165.47 ± 14.71	167.00 (152.00–178.00)
Diastolic blood pressure (mmHg)	106.27 ± 8.87	107.50 (98.50–114.00)
Duration of hypertension (years)	10.31 ± 5.70	10.00 (5.00–15.50)

Table 2: Ultrasonographic and Doppler characteristics of carotid arteries among study participants (N=104)

Parameters	**Right (Mean ± SD)**	**Left (Mean ± SD)**	**Overall mean (Mean ± SD)**
Common carotid artery (CCA)			
Intima-media thickness (mm)	1.08 ± 0.17	1.07 ± 0.18	1.08 ± 0.13
Peak systolic velocity (cm/s)	75.99 ± 11.75	74.17 ± 11.84	75.08 ± 8.46
End-diastolic velocity (cm/s)	24.35 ± 5.75	23.88 ± 5.99	24.11 ± 4.39
Resistive index	0.71 ± 0.06	0.70 ± 0.06	0.70 ± 0.04
Internal carotid artery (ICA)			
Peak systolic velocity (cm/s)	79.67 ± 23.31	86.39 ± 21.15	83.03 ± 15.31
End-diastolic velocity (cm/s)	26.96 ± 7.76	25.07 ± 8.38	26.01 ± 5.72
Resistive index	0.73 ± 0.08	0.74 ± 0.07	0.73 ± 0.05

Table 3: Distribution and ultrasonographic characteristics of carotid atherosclerotic plaques and associated stenosis

Parameters	**Frequency (n)**	**Percentage (%)**
Presence of carotid artery plaques (N=104)		
Present	49	47.1
Absent	55	52.9
Plaque morphology (n=49)		
Hyperechoic	16	32.7
Hypoechoic	16	32.7
Calcified	9	18.4
Heterogeneous	8	16.3
Severity of carotid artery stenosis (n=49)		
Mild stenosis (1–49%)	36	73.5
Moderate stenosis (50–69%)	13	26.5
Severe stenosis (≥70%)	0	0.0

Table 4: Association of carotid plaque findings with clinical characteristics and Doppler parameters, and diagnostic performance of carotid Doppler indices

A. Association of Carotid Plaque Presence with Clinical Characteristics

Characteristics	**Plaque present (n=49)**	**Plaque absent (n=55)**	**p-value**
Age group (years)			**0.048***
18–30	2 (4.1%)	10 (18.2%)	
31–45	11 (22.4%)	11 (20.0%)	
46–60	21 (42.9%)	13 (23.6%)	
61–75	15 (30.6%)	21 (38.2%)	
Gender			**0.752**
Male	22 (44.9%)	23 (41.8%)	
Female	27 (55.1%)	32 (58.2%)	
Stage of hypertension			**0.554**
Stage I	3 (6.1%)	2 (3.6%)	
Stage II	46 (93.9%)	53 (96.4%)	

Characteristics	Plaque present (n=49)	Plaque absent (n=55)	p-value
Duration of hypertension			**0.173**
≤5 years	14 (28.6%)	13 (23.6%)	
6–10 years	16 (32.7%)	11 (20.0%)	
>10 years	19 (38.8%)	31 (56.4%)	

B. Comparison of carotid Doppler parameters according to plaque status

Doppler parameters	Plaque present (n=49)	Plaque absent (n=55)	p-value
Mean CCA IMT (mm)	1.06 ± 0.15	1.10 ± 0.09	0.100
Mean CCA PSV (cm/s)	74.50 (72.15–85.90)	71.30 (67.35–79.65)	0.020*
Mean CCA EDV (cm/s)	24.65 (20.45–26.25)	24.00 (22.40–28.40)	0.377
Mean CCA RI	0.71 (0.68–0.75)	0.71 (0.67–0.73)	0.323
Mean ICA PSV (cm/s)	82.50 (71.05–94.65)	85.25 (73.10–96.10)	0.414
Mean ICA EDV (cm/s)	26.39 ± 5.02	25.68 ± 6.30	0.530
Mean ICA RI	0.72 ± 0.05	0.74 ± 0.05	0.122

C. ROC analysis of carotid Doppler parameters for predicting carotid plaque presence and moderate stenosis

Doppler parameters	AUC (plaque detection)	AUC (moderate stenosis)
Mean CCA IMT	0.601	0.624
Mean CCA PSV	0.632	0.736
Mean CCA EDV	0.550	0.583
Mean CCA RI	0.555	0.553
Mean ICA PSV	0.547	0.714
Mean ICA EDV	0.527	0.556
Mean ICA RI	0.578	0.545

A total of 104 hypertensive patients were included in the study. The mean age of the participants was 52.66 ± 15.05 years, with a median age of 53.50 years. The largest proportion belonged to the 61–75 years age group (34.6%), followed by 46–60 years (32.7%). Females constituted 56.7% of the study population, while males accounted for 43.3%. Stage II hypertension was observed in 95.2% of participants, whereas 4.8% had Stage I hypertension. The mean systolic and diastolic blood pressures were 165.47 ± 14.71 mmHg and 106.27 ± 8.87 mmHg, respectively. Regarding the duration of hypertension, 48.1% had a history of more than 10 years, while 26.0% each had hypertension for ≤5 years and 6–10 years. The mean duration of hypertension was 10.31 ± 5.70 years.

The mean common carotid artery intima–media thickness (CCA-IMT) was 1.08 ± 0.13 mm, with comparable values on the right and left sides (1.08 ± 0.17 mm and 1.07 ± 0.18 mm, respectively). The mean CCA peak systolic velocity (PSV), end-diastolic velocity (EDV) and resistive index (RI) were 75.08 ± 8.46 cm/s, 24.11 ± 4.39 cm/s and 0.70 ± 0.04, respectively. In the internal carotid artery, the corresponding mean values were 83.03 ± 15.31 cm/s for PSV, 26.01 ± 5.72 cm/s for EDV and 0.73 ± 0.05 for RI. These measurements demonstrated relatively comparable bilateral carotid Doppler parameters among the study participants.

Carotid atherosclerotic plaques were detected in 49 participants (47.1%), while 55 (52.9%) had no detectable plaques. Plaque presence showed a statistically significant association with age (p=0.048), with the 46–60 years age group contributing the largest proportion of plaque-positive cases (42.9%). However, no significant association was observed with gender (p=0.752), hypertension stage (p=0.554) or duration of hypertension (p=0.173). Comparison of Doppler parameters according to plaque status revealed significantly higher mean CCA PSV among participants with plaques than those without plaques (median 74.50 vs. 71.30 cm/s; p=0.020). No statistically significant differences were observed in CCA-IMT, CCA EDV, CCA RI, ICA PSV, ICA EDV or ICA RI between the two groups.

Among the 49 participants with carotid plaques, hyperechoic and hypoechoic plaques were equally common, each accounting for 32.7% of cases. Calcified plaques were observed in 18.4%, while heterogeneous plaques accounted for 16.3%. Plaque morphology showed significant associations with age (p=0.017), gender (p=0.034) and hypertension stage (p=0.003), whereas the association with duration of hypertension was not statistically significant (p=0.133). Comparison of Doppler parameters across plaque morphologies demonstrated significant differences in CCA-IMT (p=0.022), CCA EDV (p=0.001) and ICA PSV (p=0.010). CCA-IMT was highest in calcified plaques (1.15 ± 0.11 mm), while CCA EDV was highest in heterogeneous plaques (median 28.08 cm/s). ICA PSV was also highest in calcified plaques (median 102.15 cm/s). The remaining Doppler parameters did not show statistically significant differences across plaque morphologies.

Regarding the degree of stenosis among plaque-positive participants, mild stenosis (1–49%) was observed in 36 cases (73.5%), while moderate stenosis (50–69%) was present in 13 cases (26.5%). No severe stenosis, near occlusion or complete occlusion was detected. Stenosis severity showed a significant association with age (p=0.020) and hypertension stage (p=0.003), but not with gender (p=0.159) or duration of hypertension (p=0.262). Moderate stenosis was predominantly observed in the 46–60 years age group (76.9%). On comparison of Doppler parameters, CCA PSV was significantly higher in mild stenosis than moderate stenosis (median 76.88 vs. 72.15 cm/s; p=0.012), whereas ICA PSV was significantly higher in moderate stenosis (median 101.20 vs. 81.70 cm/s; p=0.023). Other Doppler parameters did not demonstrate statistically significant differences between the two stenosis categories.

Receiver operating characteristic analysis for plaque detection demonstrated the highest area under the curve (AUC) for CCA PSV (0.632), followed by CCA-IMT (0.601). At a criterion of greater than 71.30 cm/s, CCA PSV showed a sensitivity of 77.6% and specificity of 50.9% for plaque detection. For predicting moderate stenosis, CCA PSV showed the highest AUC (0.736), followed by ICA PSV (0.714). At a criterion of ≤74.25 cm/s, CCA PSV demonstrated a sensitivity of 84.6% and specificity of 66.7%, while ICA PSV at a criterion of greater than 92.2 cm/s showed a sensitivity of 69.2% and specificity of 88.9%. These findings indicated relatively better discriminatory performance of CCA PSV for plaque detection and moderate stenosis, although the overall AUC values suggested limited-to-moderate diagnostic discrimination.

DISCUSSION

The present study evaluated carotid arterial changes in 104 hypertensive patients using grayscale ultrasonography and Doppler assessment. The mean age was 52.66 years, and the majority of participants belonged to the older age groups. This distribution is relevant because advancing age is associated with progressive arterial wall thickening and atherosclerotic changes. The relationship between age and carotid atherosclerosis has been described in previous studies, and carotid wall measurements are recognised markers of systemic vascular changes [5, 6].

The mean CCA-IMT in the present study was 1.08 ± 0.13 mm, with similar measurements on both sides. This finding indicates increased carotid wall thickness in the study population. CIMT measurement by B-mode ultrasonography is a recognised method for assessing structural changes in the arterial wall. The Mannheim consensus emphasises standardised measurement and interpretation of CIMT, while the American Society of Echocardiography consensus supports carotid ultrasound for evaluating subclinical vascular disease and cardiovascular risk [5, 6]. However, CIMT should not be considered interchangeable with focal plaque assessment, as both provide different information regarding carotid atherosclerosis.

Carotid plaques were detected in 47.1% of participants, indicating a considerable burden of carotid atherosclerotic changes in this hypertensive population. The prevalence of plaque was significantly associated with age (p=0.048), whereas gender, hypertension stage and duration of hypertension did not demonstrate statistically significant associations. The importance of plaque assessment has been highlighted by Inaba *et al*., whose meta-analysis demonstrated that carotid plaque was more accurate than CIMT alone in predicting cerebrovascular events [7]. Polak *et al*., also demonstrated the prognostic relevance of carotid wall measurements in relation to cerebrovascular events [8]. These findings support the inclusion of plaque assessment alongside CIMT measurement during carotid ultrasonography.

In the present study, hyperechoic and hypoechoic plaques were the predominant morphological patterns, each accounting for 32.7% of plaque-positive cases. Plaque morphology showed significant associations with age, gender and hypertension stage. Furthermore, CCA-IMT, CCA EDV and ICA PSV varied significantly across plaque morphological categories. Higher CCA-IMT values were observed in calcified and heterogeneous plaques, while ICA PSV was highest in calcified plaques. These observations suggest that plaque morphology may be accompanied by differences in arterial wall thickness and haemodynamic characteristics. The assessment of plaque morphology is important because atherosclerotic plaques are heterogeneous structures, and their clinical relevance cannot be determined solely by the degree of luminal narrowing [7-10].

Mild carotid stenosis was the most common finding, accounting for 73.5% of plaque-positive cases, while moderate stenosis was observed in 26.5%. No severe stenosis or occlusion was detected. Stenosis severity was significantly associated with age and hypertension stage, although no significant association was found with gender or duration of hypertension. The Society of Radiologists in Ultrasound consensus recommends an integrated assessment using grayscale imaging, colour Doppler and spectral Doppler for the evaluation of carotid stenosis [10]. This supports the use of combined morphological and haemodynamic assessment rather than relying on a single Doppler measurement.

An important finding of the present study was the difference in PSV according to plaque status and stenosis severity. CCA PSV was significantly higher in participants with plaques than in those without plaques. However, CCA PSV was lower in moderate stenosis compared with mild stenosis, whereas ICA PSV was

significantly higher in moderate stenosis. The higher ICA PSV in moderate stenosis is consistent with the haemodynamic changes associated with luminal narrowing and supports the importance of ICA velocity assessment during stenosis grading. The relationship between carotid resistive indices and CIMT has also been investigated by Frauchiger *et al*., highlighting the complementary role of structural and Doppler-derived parameters in carotid vascular assessment [9].

ROC analysis demonstrated that CCA PSV had the highest AUC for identifying plaque presence (0.632), while CCA PSV and ICA PSV showed the highest AUC values for predicting moderate stenosis (0.736 and 0.714, respectively). Although these findings indicate relatively better performance of velocity parameters compared with the other assessed Doppler indices, the AUC values do not establish high diagnostic accuracy. Therefore, Doppler parameters should be interpreted in combination with grayscale plaque visualisation and direct assessment of luminal narrowing. The present findings support carotid Doppler ultrasonography as a useful non-invasive technique for evaluating carotid arterial structure, plaque characteristics and blood-flow changes in hypertensive patients.

CONCLUSION

Carotid Doppler ultrasonography demonstrated a substantial prevalence of carotid atherosclerotic plaques among hypertensive patients, with plaque presence significantly associated with age. CCA-IMT, plaque morphology and Doppler velocities provided complementary information regarding carotid vascular changes. CCA PSV and ICA PSV showed relatively better performance in evaluating plaque presence and moderate stenosis, respectively. Combined grayscale and Doppler assessment may therefore be useful for the non-invasive evaluation of carotid atherosclerosis in hypertensive patients.

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