

Evaluation of Carotid Intima-Media Thickness and Resistive Index in Hypertensive and Normotensive Patients Using B-Mode and Colour Doppler Sonography: A Comparative Study with Biochemical Parameters

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ABSTRACT

Background: Hypertension is a major cardiovascular risk factor that leads to structural and functional changes in the arterial wall, increasing the risk of atherosclerosis, stroke, and coronary artery disease. Carotid intima-media thickness (CMT) and carotid resistive index (RI), measured using B-mode and Colour Doppler ultrasonography, are reliable non-invasive markers of early vascular damage. This study aimed to compare CMT and RI between hypertensive and normotensive individuals and evaluate their association with biochemical parameters. **Materials and Methods:** This hospital-based observational case-control study was conducted in the Department of Radiodiagnosis and Imaging at Muzaffarnagar Medical College, Muzaffarnagar, Uttar Pradesh, over 18 months. A total of 60 participants were enrolled, including 30 patients with essential hypertension and 30 normotensive controls. All participants underwent bilateral carotid artery evaluation using B-mode and Colour Doppler ultrasonography to measure carotid intima-media thickness and resistive index. Biochemical parameters, including fasting blood sugar, total cholesterol, and serum triglycerides, were also recorded. Continuous variables were expressed as mean $\pm$ standard deviation, and a p-value <0.05 was considered statistically significant. **Results:** Hypertensive patients had significantly higher systolic and diastolic blood pressure than normotensive controls ($p<0.001$). The mean carotid intima-media thickness was significantly greater in hypertensive patients (1.18 ± 0.07 mm) than in controls (0.75 ± 0.03 mm) ($p<0.001$). Similarly, the mean carotid resistive index was significantly higher in the hypertensive group (0.737 ± 0.024) compared with controls (0.626 ± 0.013) ($p<0.001$). Mean CMT showed a strong positive correlation with systolic blood pressure ($r=0.835$, $p<0.001$), while RI correlated positively with the duration of hypertension ($r=0.689$, $p<0.001$). CMT also demonstrated significant positive correlations with total cholesterol and triglycerides. **Conclusion:** Patients with essential hypertension exhibit significantly increased carotid intima-media thickness and resistive index compared with normotensive individuals, indicating early structural and functional vascular remodelling. B-mode and Colour Doppler ultrasonography provide a simple, safe, and non-invasive method for the early detection of subclinical vascular changes. Combined assessment of carotid ultrasonographic parameters and biochemical markers may improve cardiovascular risk stratification and facilitate early therapeutic intervention.

Keywords: Essential hypertension; Carotid intima-media thickness; Resistive index; B-mode ultrasonography; Colour Doppler sonography; Atherosclerosis; Cardiovascular risk.

INTRODUCTION

Hypertension is one of the most prevalent chronic non-communicable diseases worldwide and remains a leading risk factor for cardiovascular morbidity and mortality. According to the World Health Organization (WHO), approximately 1.28 billion adults aged 30–79 years are affected by hypertension globally, with nearly two-thirds residing in low- and middle-income

countries. Despite advances in diagnosis and treatment, uncontrolled hypertension continues to contribute significantly to ischemic heart disease, stroke, heart failure, chronic kidney disease, and peripheral vascular disease.[1]

Persistent elevation of arterial blood pressure results in structural and functional alterations in the vascular wall. Long-standing hypertension accelerates

endothelial dysfunction, smooth muscle cell proliferation, arterial stiffness, and atherosclerotic changes, ultimately increasing the risk of cardiovascular events.[2] Detection of these vascular changes at an early stage is therefore essential for appropriate risk stratification and timely intervention. Carotid intima-media thickness (CIMT) is a well-established non-invasive marker of early atherosclerosis and vascular remodeling. It represents the combined thickness of the intimal and medial layers of the carotid artery and can be accurately measured using high-resolution B-mode ultrasonography. Increased CIMT has been shown to correlate with cardiovascular risk factors and is considered an independent predictor of myocardial infarction and stroke.[3,4]

Color Doppler ultrasonography further complements B-mode imaging by evaluating hemodynamic parameters such as the carotid resistive index (RI). RI reflects downstream vascular resistance and arterial compliance and provides valuable information regarding functional vascular alterations. Elevated RI has been associated with increased arterial stiffness, endothelial dysfunction, and target organ damage in hypertensive patients.[5,6]

In addition to vascular imaging, biochemical parameters such as fasting blood sugar, serum cholesterol, triglycerides, and lipoproteins play an important role in cardiovascular risk assessment. Dyslipidemia and impaired glucose metabolism accelerate endothelial injury and atherosclerotic plaque formation, thereby contributing to increased CIMT and vascular resistance.[7] Several investigators have demonstrated significant correlations between lipid abnormalities, carotid artery changes, and hypertension severity.[8]

B-mode and Color Doppler sonography are safe, non-invasive, inexpensive, and widely available imaging modalities capable of detecting early vascular changes before the onset of clinically evident cardiovascular disease. Their combined use provides comprehensive assessment of both structural and functional arterial abnormalities and may improve cardiovascular risk prediction in hypertensive individuals.[9]

Although several studies have evaluated CIMT or Doppler indices individually, relatively few have simultaneously assessed carotid intima-media thickness, resistive index, and biochemical parameters in patients with essential hypertension in the Indian population. The present study was therefore undertaken to compare carotid intima-media thickness and resistive index between hypertensive and normotensive individuals using B-mode and Color Doppler sonography and to evaluate their association with biochemical parameters.

MATERIALS AND METHODS

Study Design and Setting

This hospital-based observational case-control study was conducted in the Department of Radiodiagnosis and Imaging, Muzaffarnagar Medical College, Muzaffarnagar, Uttar Pradesh, India. The study was carried out over a period of 18 months, including 12 months for patient recruitment and data collection, followed by 6 months for data analysis.

Study Population

The study included patients with clinically diagnosed essential hypertension attending the Department of Radiodiagnosis and Imaging. Apparently healthy normotensive individuals fulfilling the eligibility criteria were included as controls.

Sample Size and Sampling

A total of 60 participants were enrolled, comprising 30 patients with essential hypertension (cases) and 30 normotensive individuals (controls). Participants were selected using a purposive sampling technique, and eligible subjects were recruited consecutively until the required sample size was achieved.

The sample size was determined based on the availability of eligible patients during the study period and previous similar studies.

Eligibility Criteria

Inclusion Criteria

- Patients diagnosed with essential hypertension for more than 5 years.
- Age >30 years.
- Both male and female participants.
- Normotensive individuals fulfilling the eligibility criteria were included as controls.

Exclusion Criteria

- Secondary hypertension.
- Malignant hypertension.
- Diabetes mellitus.
- History of smoking or alcoholism.
- Individuals unwilling to participate.

Study Procedure

Written informed consent was obtained from all participants before enrollment. A detailed clinical history, including duration of hypertension and family history of hypertension, was recorded. Hypertension was defined according to the Seventh Joint National Committee (JNC-7) criteria as systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg.

All participants underwent bilateral carotid ultrasonography and Doppler examination using a Samsung HS50 ultrasound machine equipped with a high-frequency linear array transducer.

Carotid intima-media thickness (CIMT) was measured on the far wall of the common carotid artery, 1–2 cm proximal to the carotid bulb, using an optimal longitudinal frozen image. CIMT was defined as the distance between the leading edge of the lumen–intima interface and the leading edge of the media–adventitia interface. Measurements were obtained by manual cursor placement using appropriate image magnification.

Colour Doppler examination of both carotid arteries was performed. The Resistive Index (RI) was calculated automatically by the ultrasound system using peak systolic and end-diastolic flow velocities through the inbuilt software.

Biochemical Assessment

The following biochemical parameters were recorded as part of the routine diagnostic work-up:

- Fasting blood sugar (FBS)
- Total cholesterol
- Serum triglycerides

Study Variables

The primary study variables were:

- Carotid intima-media thickness (CIMT)

- Carotid resistive index (RI)
- Biochemical parameters (FBS, total cholesterol, and triglycerides)

Statistical Analysis

Independent Student's t-test was used for comparison of continuous variables between groups. Chi-square test was used for categorical variables. Pearson's correlation coefficient was used to assess the relationship between vascular parameters and biochemical variables. A p-value <0.05 was considered statistically significant.

Ethical Considerations

The study was approved by the Institutional Ethics Committee of Muzaffarnagar Medical College, Muzaffarnagar, Uttar Pradesh. Written informed consent was obtained from all participants before inclusion in the study.

Informed Consent

Written informed consent was obtained from all participants prior to enrolment in the study.

RESULTS AND OBSERVATIONS

A total of 60 participants were included in the study, comprising 30 hypertensive patients (cases) and 30 normotensive individuals (controls). Hypertensive patients demonstrated significantly higher blood pressure, carotid intima-media thickness (cIMT), and carotid resistive index (RI) than controls. Significant positive correlations were observed between vascular parameters and blood pressure, hypertension duration, and lipid profile.

Table 1. Baseline Characteristics of the Study Population

Variable	Hypertensive (n=30)	Controls (n=30)	p-value
Age (years)	55.23 ± 5.11	46.43 ± 3.34	<0.001
Male, n (%)	19 (63.3)	16 (53.3)	0.432
Female, n (%)	11 (36.7)	14 (46.7)	

Observation: Hypertensive patients were significantly older than controls, while gender distribution was comparable.

Table 2. Comparison of Blood Pressure Between Study Groups

Parameter	Hypertensive	Controls	p-value
Systolic BP (mmHg)	159.63 ± 8.41	121.90 ± 4.41	<0.001
Diastolic BP (mmHg)	97.63 ± 5.12	78.77 ± 3.01	<0.001

Observation: Both systolic and diastolic blood pressure were significantly higher among hypertensive patients.

Table 3. Comparison of Carotid Intima-Media Thickness (cIMT)

Parameter	Hypertensive	Controls	p-value
Right CCA cIMT (mm)	1.20 ± 0.08	0.77 ± 0.04	<0.001
Left CCA cIMT (mm)	1.18 ± 0.08	0.74 ± 0.04	<0.001
Mean cIMT (mm)	1.18 ± 0.07	0.75 ± 0.03	<0.001

Observation: Mean cIMT was significantly greater in hypertensive patients, indicating increased arterial wall thickness.

Table 4. Comparison of Carotid Resistive Index (RI)

Parameter	Hypertensive	Controls	p-value
Right RI	0.744 ± 0.025	0.626 ± 0.014	<0.001
Left RI	0.731 ± 0.025	0.625 ± 0.013	<0.001
Mean RI	0.737 ± 0.024	0.626 ± 0.013	<0.001

Observation: Mean RI was significantly higher in hypertensive patients, suggesting increased peripheral vascular resistance.

Table 5. Biochemical Parameters Recorded

Parameter	Assessment
Fasting Blood Sugar	Recorded
Total Cholesterol	Recorded
Triglycerides	Recorded

Observation: Biochemical investigations were performed in all study participants as part of the diagnostic evaluation.

Table 6. Correlation of Mean cIMT and Mean RI with Clinical Variables

Correlation	r-value	p-value
Mean cIMT vs Systolic BP	0.835	<0.001
Mean RI vs Duration of Hypertension	0.689	<0.001

Observation: Mean cIMT showed a strong positive correlation with systolic blood pressure, while RI increased significantly with longer duration of hypertension.

Table 7. Correlation of Mean cIMT with Lipid Profile

Parameter	r-value	p-value
Total Cholesterol	0.907	<0.001
LDL Cholesterol	0.918	<0.001
HDL Cholesterol	-0.907	<0.001
Triglycerides	0.896	<0.001

Observation: Mean cIMT was positively correlated with total cholesterol, LDL cholesterol, and triglycerides, whereas HDL cholesterol showed a strong negative correlation.

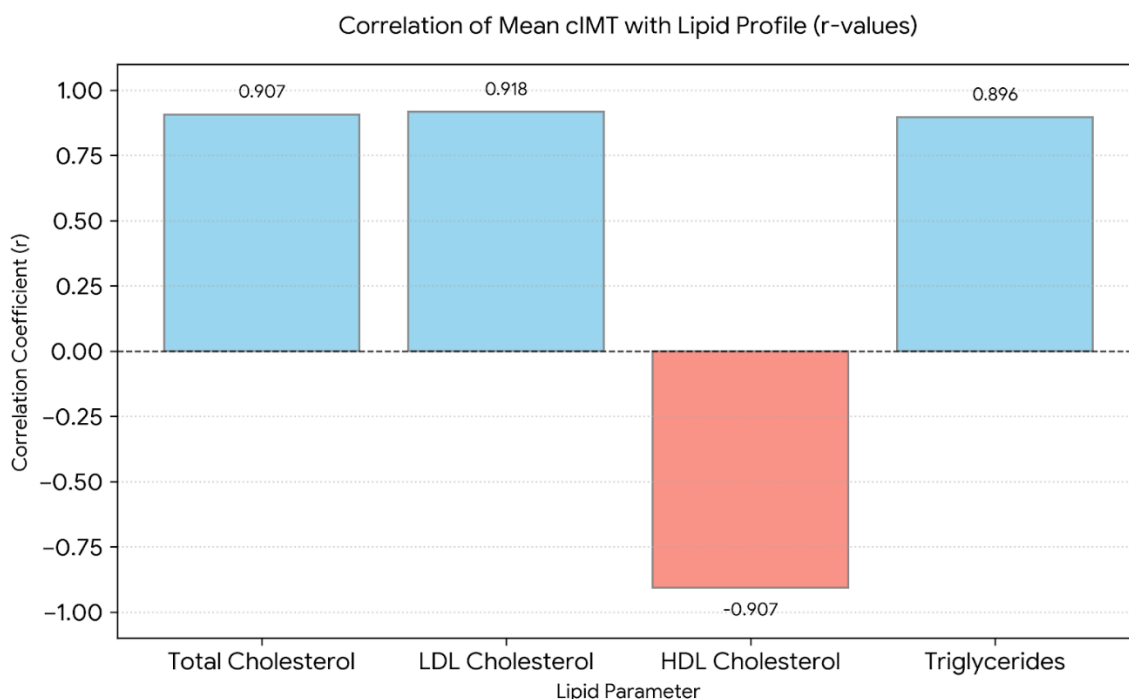


Table 8. Vascular Abnormalities Among Study Groups

Variable	Hypertensive	Controls	p-value
Increased cIMT	Present in majority	Rare/Absent	<0.001
Increased RI	Present in majority	Rare/Absent	<0.001

Observation: Structural and functional vascular abnormalities were predominantly observed among hypertensive patients.

Table 9. Summary of Significant Findings

Variable	Finding
Age	Higher in hypertensive patients
Blood Pressure	Significantly elevated
Mean Cimt	Significantly increased
Mean RI	Significantly increased
Correlation with SBP	Strong positive
Correlation with Duration of HTN	Moderate positive
Correlation with Lipid Profile	Significant positive (HDL negative)

Observation: Hypertension was associated with both structural and functional carotid artery changes.

Table 10. Overall Comparison Between Cases and Controls

Parameter	Hypertensive (n=30)	Controls (n=30)	p-value
Age (years)	55.23 ± 5.11	46.43 ± 3.34	<0.001
SBP (mmHg)	159.63 ± 8.41	121.90 ± 4.41	<0.001
DBP (mmHg)	97.63 ± 5.12	78.77 ± 3.01	<0.001
Mean cIMT (mm)	1.18 ± 0.07	0.75 ± 0.03	<0.001
Mean RI	0.737 ± 0.024	0.626 ± 0.013	<0.001

Observation: Hypertensive patients had significantly higher blood pressure, carotid intima-media thickness, and resistive index than normotensive controls, supporting the presence of early vascular remodelling associated with essential hypertension.

DISCUSSION

The present hospital-based case-control study compared carotid intima-media thickness (CMT) and carotid resistive index (RI) between patients with essential hypertension and normotensive controls using B-mode and Colour Doppler ultrasonography. The study also evaluated the relationship of these vascular parameters with selected biochemical markers. The findings demonstrated significantly higher CMT and RI among hypertensive patients, suggesting early structural and functional vascular remodelling associated with chronic hypertension.

The mean age of hypertensive patients was significantly higher than that of controls. Increasing age is a recognised independent determinant of arterial stiffness and vascular wall thickening due to progressive degeneration of elastic fibres, collagen deposition, and endothelial dysfunction. Similar observations have been reported in several epidemiological studies demonstrating an age-dependent increase in carotid intima-media thickness.[3,10]

As expected, both systolic and diastolic blood pressure were significantly elevated in hypertensive patients. Chronic exposure to increased intraluminal pressure induces adaptive hypertrophy of the arterial wall, promotes smooth muscle cell proliferation, and accelerates extracellular matrix deposition, resulting in increased arterial wall thickness and reduced vascular compliance.[2,11]

The present study demonstrated significantly greater mean CMT in hypertensive individuals compared with normotensive controls. These findings are consistent with those reported by Bots et al., who demonstrated that carotid intima-media thickness is an important surrogate marker of generalised

atherosclerosis and predicts future cardiovascular events.[3] Similarly, Lorenz et al. reported in a systematic review that increased CMT is strongly associated with myocardial infarction and stroke independent of conventional cardiovascular risk factors.[4] Increased CMT in hypertensive patients likely reflects chronic endothelial injury and accelerated vascular remodelling induced by sustained hypertension.

Carotid resistive index was also significantly higher in hypertensive patients. Increased RI reflects elevated peripheral vascular resistance and decreased arterial compliance secondary to vascular remodelling. These findings are comparable with previous Doppler studies that have shown significantly elevated RI in hypertensive individuals and its association with target organ damage and arterial stiffness.[5,12] Doppler-derived RI therefore provides important functional information that complements structural assessment obtained by CMT measurement.

A strong positive correlation was observed between mean CMT and systolic blood pressure in the present study. Similar associations have been reported by O'Leary et al., who found carotid wall thickness to increase proportionately with increasing blood pressure and cardiovascular risk.[13] Elevated systolic pressure increases circumferential wall stress, promoting vascular hypertrophy and intimal thickening.

The present study also demonstrated a significant positive correlation between RI and duration of hypertension, indicating progressive deterioration in vascular function with prolonged disease duration. Long-standing hypertension causes irreversible arterial wall changes, increased vascular resistance, and reduced vessel elasticity. Previous longitudinal studies

have similarly demonstrated worsening arterial stiffness with increasing duration of hypertension.[14] Significant positive correlations were observed between CIMT and serum total cholesterol, LDL cholesterol, and triglycerides, whereas HDL cholesterol showed a significant negative correlation. These findings support the established role of dyslipidemia in accelerating atherosclerosis. Elevated LDL cholesterol promotes lipid deposition within the arterial wall, oxidative modification, and inflammatory responses leading to intimal thickening, whereas HDL cholesterol exerts protective anti-inflammatory and reverse cholesterol transport effects.[7,15]

The majority of hypertensive patients exhibited increased CIMT and elevated RI compared with normotensive controls, indicating that both structural and functional carotid artery abnormalities occur even before clinically overt cardiovascular complications develop. These observations highlight the value of carotid ultrasonography as a simple, reproducible, and non-invasive method for identifying individuals at increased cardiovascular risk.

The combined evaluation of B-mode sonographic CIMT and Doppler-derived RI provides complementary information regarding vascular remodelling in essential hypertension. Incorporating these parameters into routine evaluation of hypertensive patients may facilitate earlier detection of subclinical vascular disease, improved cardiovascular risk stratification, and more effective therapeutic interventions.

The present study had certain limitations. The sample size was relatively small, and participants were recruited from a single tertiary care centre, which may limit generalizability. The cross-sectional design precluded assessment of temporal changes and causal relationships. Larger multicenter prospective studies with long-term follow-up are warranted to validate these findings and determine the prognostic value of carotid ultrasonographic parameters in hypertensive patients.

Overall, the present study demonstrates that hypertensive patients exhibit significantly increased carotid intima-media thickness and resistive index compared with normotensive individuals. These vascular changes are closely associated with blood pressure levels, duration of hypertension, and lipid abnormalities, emphasising the usefulness of carotid ultrasonography as an effective tool for early cardiovascular risk assessment.

Strengths of the Study

The present study simultaneously evaluated both structural (carotid intima-media thickness) and functional (carotid resistive index) vascular changes using B-mode and Colour Doppler ultrasonography in patients with essential hypertension. In addition, the association of these ultrasonographic parameters with biochemical markers provided a comprehensive

assessment of cardiovascular risk. The inclusion of a normotensive control group further strengthened the comparative analysis and enhanced the clinical relevance of the findings.

Future Recommendations

Future multicentre studies with larger sample sizes and longer follow-up periods are recommended to validate the present findings and determine the prognostic value of carotid intima-media thickness and resistive index in predicting cardiovascular outcomes. Further research should also evaluate the impact of antihypertensive therapy and lipid-lowering interventions on carotid vascular parameters and explore their role in routine cardiovascular risk assessment.

CONCLUSION

The present study demonstrated that patients with essential hypertension have significantly increased carotid intima-media thickness (CIMT) and carotid resistive index (RI) compared with normotensive individuals, indicating early structural and functional vascular changes. Both CIMT and RI showed significant positive correlations with blood pressure, duration of hypertension, and adverse lipid profile. These findings suggest that B-mode and Colour Doppler ultrasonography are reliable, non-invasive tools for the early detection of subclinical vascular damage in hypertensive patients. Combined assessment of carotid ultrasonographic parameters and biochemical markers may aid in cardiovascular risk stratification and facilitate timely preventive and therapeutic interventions.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Author Contributions

All authors contributed to the conception and design of the study, data collection, data analysis, manuscript preparation, critical revision, and approved the final manuscript.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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