ORIGINAL ARTICLE

PATTERNS OF LEFT VENTRICULAR HYPERTROPHY AND REMODELLING IN PAKISTANI PATIENTS WITH UNCONTROLLED HYPERTENSION: RELATIONSHIP WITH DURATION OF DISEASE, MEDICATION ADHERENCE, AND SALT INTAKE PROXIES

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Background: Left ventricular (LV) geometric remodelling is a common consequence of uncontrolled hypertension and is associated with adverse cardiovascular outcomes. Various clinical (duration of hypertension) and behavioural (adherence with medication and salt-intake) factors may influence LV geometry patterns. The o**bjectives of this study were** to determine the distribution of left ventricular geometry and to assess its association with duration of hypertension, medication adherence, and salt intake among patients with uncontrolled hypertension. **Methods:** A cross-sectional study conducted at Peshawar Institute of Cardiology. A total of 140 patients with uncontrolled hypertension were enrolled through consecutive sampling. Clinical data, duration of hypertension, medication adherence, and salt intake were recorded. Echocardiography was performed to assess left ventricular mass index (LVMI) and relative wall thickness (RWT), and LV geometry was classified into normal geometry, concentric remodelling, concentric hypertrophy, and eccentric hypertrophy. Data were analysed using SPSS-25. Chi-square test was applied to determine associations, and $p \leq 0.05$ was considered statistically significant. **Results:** The mean age of participants was 52.3±10.1 years, with 55.7% males. Concentric hypertrophy was the most prevalent LV geometric pattern (32.9%), followed by normal geometry (24.3%), concentric remodelling (21.4%), and eccentric hypertrophy (21.4%). No statistically significant association was observed between LV geometry and duration of hypertension (p=0.694), medication adherence (p=0.524), or salt intake (p=0.585). **Conclusion:** Concentric hypertrophy was the predominant LV geometric pattern among patients with uncontrolled hypertension. Duration of hypertension, medication adherence, and salt intake were not significantly associated with LV geometry in this study population.

Keywords: Concentric hypertrophy, Hypertension, Left ventricular geometry, Medication adherence, Salt intake

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INTRODUCTION

Hypertension is a chronic cardiovascular disorder characterized by persistently elevated systemic arterial blood pressure and remains one of the leading modifiable risk factors for cardiovascular morbidity and mortality worldwide.[1] Sustained pressure overload primarily affects the left ventricle, leading to structural adaptations collectively referred to as left ventricular hypertrophy (LVH) and ventricular remodelling. LVH represents an increase in left ventricular mass due to myocardial cell enlargement, while remodelling reflects alterations in ventricular geometry, including concentric hypertrophy, eccentric hypertrophy, and concentric remodelling. These geometric patterns have important prognostic implications, particularly in patients with uncontrolled hypertension.[2]

Globally, hypertension affects more than one billion individuals and contributes substantially to ischemic heart disease, stroke, heart failure, and premature mortality.[3] The burden is particularly high in low- and middle-income countries. In South Asia, the prevalence of hypertension ranges from 25 to 35% among adults, with higher rates reported in urban populations.[4] Despite the availability of effective pharmacological therapies, blood pressure control remains suboptimal in many patients, accelerating target-organ damage, particularly structural cardiac changes that increase long-term cardiovascular risk.

The development of hypertensive LVH is multifactorial. Persistent elevation of systemic vascular resistance imposes chronic afterload on the left ventricle, stimulating compensatory myocardial hypertrophy. The duration of hypertension plays a key role, as prolonged exposure to elevated blood pressure enhances myocardial stress and structural adaptation. In addition, medication adherence significantly influences disease progression, as poor adherence leads to sustained uncontrolled blood pressure and accelerates cardiac remodelling. High dietary sodium intake, common in South Asian populations, is another important contributor. Other factors such as age, obesity, diabetes mellitus, dyslipidaemia, and genetic susceptibility may further influence the extent and pattern of ventricular hypertrophy.[5]

The pathophysiology of left ventricular remodelling involves complex hemodynamic and neurohormonal mechanisms. Chronic pressure overload increases myocardial wall stress, leading to adaptive myocyte hypertrophy aimed at maintaining wall tension. Activation of the rennin-angiotensin-aldosterone system (RAAS) and sympathetic nervous system promotes myocardial fibrosis and extracellular matrix deposition, resulting in alterations in ventricular geometry.[6] Concentric hypertrophy develops in response to pressure overload and is characterized by increased wall thickness. Eccentric hypertrophy may occur when volume overload coexists. Over time, these structural changes impair diastolic relaxation and ventricular compliance and may progress to systolic dysfunction and overt heart failure.[7]

Left ventricular hypertrophy often remains asymptomatic in early stages but may eventually lead to symptoms such as exertional dyspnoea, reduced exercise tolerance, palpitations, and angina-like chest discomfort. The presence of LVH significantly increases the risk of atrial fibrillation, ventricular arrhythmias, ischemic heart disease, heart failure, and sudden cardiac death.[7] Diagnosis primarily relies on assessment of left ventricular mass index (LVMI), wall thickness, and geometric patterns on echocardiography. Management focuses on optimal blood pressure control using antihypertensive therapy along with sodium restriction, weight reduction, and regular physical activity.[8]

Although regression of LVH is associated with improved cardiovascular outcomes, limited local data exist regarding patterns of left ventricular remodelling in Pakistani patients with uncontrolled hypertension and the role of modifiable factors such as disease duration, medication adherence, and salt intake. Understanding these relationships may help improve risk stratification and preventive strategies in this population.

MATERIAL AND METHODS

This cross-sectional analytical study was conducted at the Department of Cardiology, Peshawar Institute of Cardiology over a period of six months from June to November 2025. A total of 140 patients with uncontrolled hypertension were enrolled using non-probability consecutive sampling. Uncontrolled hypertension was defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg on at least two separate readings despite ongoing antihypertensive therapy or documented poor blood pressure control in known hypertensive patients.[9] Adult patients aged 30–70 years of either gender with a confirmed diagnosis of primary hypertension for at least one year were included. Patients with secondary hypertension, known valvular heart disease, congenital heart disease, cardiomyopathy unrelated to hypertension, ischemic heart disease with prior myocardial infarction, chronic kidney disease stage IV or above, and pregnant women were excluded to minimize confounding structural cardiac changes.

The sample size was calculated using Daniel's formula (utilized in WHO guidelines for single proportions in cross-sectional studies) taking anticipated frequency of left ventricular hypertrophy as 50%[4], confidence level of 95%, and a margin of error of 8%. The calculated sample size was 150; however, after accounting for feasibility and expected complete data availability, 140 patients were included in final analysis.

After obtaining approval from the institutional ethical review committee and written informed consent from the participants, demographic and clinical data were recorded using a structured proforma. Information regarding age, gender, duration of hypertension, current antihypertensive medication, and comorbidities was documented. Duration of disease was categorized into ≤5 years, 6–10 years, and >10 years based on patient history and medical records. Medication adherence was assessed using a structured self-reported validated adherence questionnaire[10], and patients were categorized as adherent or non-adherent based on standard scoring criteria. Salt intake proxies were evaluated through dietary history, including frequency of adding extra salt to meals, consumption of processed or salted foods, and self-reported high-salt dietary habits.

Blood pressure was measured on a mercury sphygmomanometer with the patient in a seated position. Patients underwent transthoracic echocardiography by an experienced cardiologist using a standardized protocol. Left ventricular mass was calculated using the Devereux formula, and left ventricular mass index (LVMI) was derived by indexing to body surface area. Left ventricular hypertrophy was defined according to established gender-specific cut-off values of LVMI (≥115 g/m^2 for males and ≥95 g/m^2 for females). Relative wall thickness was calculated to determine geometric patterns. Based on LVMI and relative wall thickness, patients were classified into normal geometry, concentric remodelling, concentric hypertrophy, or eccentric hypertrophy.

Data were analysed using SPSS-29. Quantitative variables such as age, duration of hypertension, blood pressure, and LVMI were expressed as Mean±SD, while qualitative variables such as gender, adherence status, salt intake category, and remodelling patterns were expressed as frequencies and percentages. The association between patterns of left ventricular remodelling and duration of disease, medication adherence, and salt intake proxies was assessed using Chi-square test, and $p \leq 0.05$ was considered statistically significant.

RESULTS

The study population comprised of 140 patients with a mean age of 52.3±10.1 years. Male participants accounted for 55.7% of the cohort, whereas females constituted 44.3%. Regarding duration of hypertension, 34.3% had hypertension for ≤5 years, 40.0% for 6–10 years, and 25.7% for more than 10 years. Most (65.7%) patients were adherent to medications, while 34.3% were non-adherent; and 27.1% had low, 40.0% moderate, and 32.9% had high salt intake (Table-1).

The systolic blood pressure (SBP) ranged from 140 to 180 mmHg (mean 160.97±11.37) and diastolic blood pressure (DBP) from 90 to 110 mmHg (mean 100.01±5.80). Left ventricular mass ranged from 160 to 299 g (236.40±42.16 g), and the left ventricular mass index (LVMI) ranged from 96 to 160 g/m², (129.49±18.54 g/m²). Relative wall thickness (RWT) varied between 0.34 and 0.65 (0.49±0.09).

Overall distribution of left ventricular geometry indicated that 24.3% patients had normal geometry, 21.4% had concentric remodelling, 32.9% had concentric hypertrophy, and 21.4% had eccentric hypertrophy, showing a predominance of concentric hypertrophy among the study population (Table-2).

When stratified by duration of hypertension, patients with hypertension of 6–10 years showed the highest proportion of concentric hypertrophy (47.8%), whereas those with <5 years of hypertension had a relatively higher proportion of eccentric hypertrophy (43.3%). Normal geometry was more common among patients with 6–10 years of hypertension (41.2%), and concentric remodelling was fairly evenly distributed across all duration categories. There was no statistically significant association between duration of hypertension and left ventricular geometry (p=0.694), (Table-3).

Patients adherent to medication had a higher prevalence of concentric hypertrophy (37.0%) compared with non-adherent patients (25.0%). Normal geometry was more common among non-adherent patients (29.2%) than adherent patients (21.7%). Concentric remodelling and eccentric hypertrophy were distributed similarly between the two groups. The Chi-square analysis demonstrated no statistically significant relationship between medication adherence and left ventricular geometry (p=0.524), (Table-4).

Concentric hypertrophy was most frequent among patients with moderate salt intake (39.3%), while eccentric hypertrophy was slightly higher among those with high salt intake (21.7%) compared with low intake (21.1%). Normal geometry was most commonly observed in patients with high salt intake (28.3%). Concentric remodelling appeared highest in the low salt intake group (28.9%). No statistically significant association was found between salt intake and left ventricular geometry (p=0.585), (Table-5).

Table-1: Demographic and clinical characteristics of study participants (n=140)

Variable	Category	n (%)
Age (Mean age: 52.3±10.1 Years)	30–39	18 (12.9)
	40–49	40 (28.6)
	50–59	44 (31.4)
	60–70	38 (27.1)
Gender	Male	78 (55.7)
	Female	62 (44.3)
Duration of Hypertension	≤5 years	48 (34.3)
	6–10 years	56 (40.0)
	>10 years	36 (25.7)
Medication Adherence	Adherent	92 (65.7)
	Non-Adherent	48 (34.3)
Salt Intake Proxy	Low	38 (27.1)
	Moderate	56 (40.0)
	High	46 (32.9)

Table-2: Distribution of left ventricular geometry among study participants (n=140)

LV Geometry Category	n (%)
Normal	34 (24.3)
Concentric Remodelling	30 (21.4)
Concentric Hypertrophy	46 (32.9)
Eccentric Hypertrophy	30 (21.4)

Table-3: LV geometry stratified by duration of hypertension [n (%)]

Duration of Hypertension	Normal	Concentric Remodelling	Concentric Hypertrophy	Eccentric Hypertrophy
<5 years	11 (32.4)	9 (30.0)	15 (32.6)	13 (43.3)
6–10 years	14 (41.2)	11 (36.7)	22 (47.8)	9 (30.0)
>10 years	9 (26.5)	10 (33.3)	9 (19.6)	8 (26.7)
Total	34 (24.3)	30 (21.4)	46 (32.9)	30 (21.4)

χ^2=3.873, df=6, p=0.694

Table-4: LV Geometry stratified by medication adherence (n=140)

Medication Adherence	Normal	Concentric Remodelling	Concentric Hypertrophy	Eccentric Hypertrophy
Adherent	20 (21.7)	19 (20.7)	34 (37.0)	19 (20.7)
Non-Adherent	14 (29.2)	11 (22.9)	12 (25.0)	11 (22.9)
Total	34 (24.3)	30 (21.4)	46 (32.9)	30 (21.4)

χ^2=2.240, df=3, p=0.524

Table-5: LV Geometry stratified by salt intake

Salt Intake	Normal	Concentric Remodelling	Concentric Hypertrophy	Eccentric Hypertrophy
Low	7 (18.4)	11 (28.9)	12 (31.6)	8 (21.1)
Moderate	14 (25.0)	8 (14.3)	22 (39.3)	12 (21.4)
High	13 (28.3)	11 (23.9)	12 (26.1)	10 (21.7)
Total	34 (24.3)	30 (21.4)	46 (32.9)	30 (21.4)

χ^2=4.687, df=6, p=0.585

DISCUSSION

Hypertension remains a major global public health challenge and a leading cause of cardiovascular morbidity and mortality. Persistent elevation of blood pressure leads to structural and functional cardiac alterations, particularly changes in left ventricular (LV) geometry, which are recognized predictors of adverse cardiovascular outcomes.[11–13] In the present study, concentric hypertrophy emerged as the most prevalent LV geometric pattern, followed by normal geometry,

concentric remodelling, and eccentric hypertrophy. These findings indicate a substantial burden of maladaptive myocardial remodelling among patients with persistently uncontrolled blood pressure.

Our results are consistent with those reported by Hahkan *et al*[14] and Khan *et al*[15], who observed high prevalence of LVH among hypertensive patients and significantly higher left ventricular mass (LVM) and left ventricular mass index (LVMI) in uncontrolled compared with controlled hypertensive individuals. Although our study focused on geometric patterns rather than overall LVH prevalence, the predominance of concentric hypertrophy and elevated mean LVMI support the association between uncontrolled hypertension and adverse cardiac remodelling in Pakistani populations.

In contrast, Masood *et al*[16] reported a lower prevalence of LVH among newly diagnosed hypertensive patients. Their cohort included younger individuals with recently diagnosed hypertension, whereas our study involved patients with established and uncontrolled disease. This difference likely explains the higher LVMI and greater prevalence of concentric hypertrophy observed in our population, highlighting the progressive nature of LV remodelling with prolonged hypertension and inadequate blood pressure control.

Although a trend toward increased concentric hypertrophy with longer disease duration was observed, no statistically significant association was identified. This finding differs from the study by Adeseye *et al*[17] who reported larger ventricular dimensions in patients with longer disease duration and identified concentric remodelling as the most common geometric pattern. Differences in treatment status, blood pressure control, and population characteristics may explain these variations, as their cohort included treated hypertensive patients whereas our study focused on individuals with uncontrolled hypertension.

No significant association was found between salt intake and LV geometry. Previous studies using 24-hour urinary sodium measurements, such as those by Cailar *et al*[18] have demonstrated a positive association between sodium intake and LVMI. Other investigations, including those by Nista *et al*[19] and Van der Westhuizen *et al*[20] have also reported significant relationships between sodium excretion and increased cardiac mass. Lack of association in our study may be attributed to the use of dietary proxy measures rather than objective sodium assessments, as well as limited statistical power.

Medication adherence also showed no significant relationship with LV geometry, although adherent patients demonstrated a slightly higher proportion of concentric hypertrophy. These findings are consistent with Kamasova *et al*[21] who reported only a weak inverse correlation between adherence and LVMI.

Overall, the absence of statistically significant associations in our study reflects the multifactorial nature of LV remodelling in hypertension, where hemodynamic load, neurohormonal activation, and genetic factors interact with behavioural determinants such as medication adherence and dietary habits.

A major strength of this study is the echocardiographic evaluation of LV geometry using standardized parameters (LVMI and RWT). However, several limitations should also be acknowledged. The cross-sectional design precludes causal inference, and the moderate sample size may have limited statistical power. Salt intake was assessed indirectly through dietary history rather than objective sodium measurements.

CONCLUSION

Concentric hypertrophy was the most prevalent LV geometric pattern among patients with uncontrolled hypertension. No significant association was found between LV geometry and duration of hypertension, medication adherence, or salt intake. Further large-scale prospective studies are required to clarify determinants of LV remodelling in hypertensive patients.

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The author approved the draft and is accountable in ensuring that questions related to accuracy or integrity of the work are duly investigated and resolved.
MM: Concept, Study design, Data analysis, Manuscript drafting **AR:** Supervision, Data interpretation
AW: Study design, Data collection, Data interpretation **SR:** Data collection, Statistical analysis

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