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ECHOCARDIOGRAPHY FINDINGS OF LEFT VENTRICULAR IN PATIENT WITH CONTROLLED AND UNCONTROLLED HYPERTENSION

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ABSTRACT

Background: *Hypertension is a common malignant disease that adversely affects cardiovascular health, particularly left ventricle function and structure. Under high blood pressure, the left ventricle changes structurally and functionally. These changes have features of left ventricular hypertrophy (LVH) and possible heart failure. This study aimed to determine the prevalence and severity of left ventricular hypertrophy (LVH) and left ventricular diastolic dysfunction and to identify the differences in left ventricular ejection fraction (LVEF) between controlled and uncontrolled hypertension patients.*

Methods*: This comparative cross-sectional study included 200 hypertensive patients (100 controlled and 100 uncontrolled) using convenience sampling methods at the Peshawar Institute of Cardiology. Screening for eligibility was based on inclusion and exclusion criteria. Ethical approval was obtained and data was collected after informed consent and echocardiography test, and SPSS/GraphPad Prism was used for analysis.*

Results: *A statistically significant difference found between controlled and uncontrolled hypertensive groups. The fact of having poor-control hypertensive patient demographic shows a greater prevalence of left ventricular hypertrophy (70% vs. 40%) and diastolic dysfunction (63% vs. 37%), alongside significantly greater left ventricular mass index; (125±15 g/m² vs. 95±12 g/m²). The uncontrolled cohort had a poorer mean left ventricular ejection fraction (55±7% vs. 60±5%) and higher evidence of systolic dysfunction (30% vs. 10%). Regarding gender distribution, poor control involved more males (60% vs. 55%) and a slightly older average age (52.1±8.5 years vs. 50.3±7.8 years). Mean structural remodeling associated with uncontrolled hypertension was found to be statistically highly significant ($p < 0.0001$).*

Conclusions: *This research study gives deep understandings into the separate effects of controlled and uncontrolled hypertension on left ventricular remodeling. It highlights the strong association between blood pressure control and cardiac health and emphasizes that individualized management would improve clinical outcomes.*

Keywords: *Left Ventricle, Blood Pressure, Left Ventricular Mass Index, Ejection Fraction, Hypertension*

INTRODUCTION

Hypertension, more commonly called high blood pressure, is probably the greatest global health challenge, affects more than 1.13 billion people in the worldwide (1). In addition to being "the silent

killer," it goes unnoticed with time when vascular systems are being damaged insidiously. The results are known to be severe, including MI, heart failure, strokes, and kidney failure. Apart from this, it has also become a major cost to individuals, whether direct or indirect, making hypertension a huge burden to almost every public health agenda. Hypertension is an important global health problem, but management has region-specific variations. About 47% of adults suffer from hypertension in the United States, but just about 24% can get the condition under control, owing to healthcare access gaps, economic inequalities and lifestyle factors like obesity and high-sodium diets, especially in underserved areas of the South (2).

Over 30% of adults in India are hypertensive, but only 12% of them have their condition effectively controlled. The already strained healthcare infrastructure of the country, little public awareness, and changes in lifestyle due to urbanization add to this problem. Most of the gap in that regard is being attempted by initiatives such as the India Hypertension Control Initiative that advocate common treatment and are working to improve access to medications (3). China has 244 million hypertensive individuals; however, this problem will be aggravated by an elderly population, a diet that is generally considered high in salt, and health care systems in rural areas that are very limited. The "Salt Reduction Campaign" and mobile health technologies show promise. Still, their measurement scale or widescale implementation across the country continues to be challenging because the weigh-in study also revealed a high proportion of salt intake disparity, Hypertension affects up to 46% of urban adults in Sub-Saharan Africa, and only about 10% have been found to receive adequate treatment due to structural deficiencies and low awareness (4).

Unfortunately, advanced care is still needed in rural dwellings despite these positive effects. In Germany, 30% of adults, or about 24 million of them, are found to have high blood pressure; of those 50% control their risks (5). High alcohol consumption and associated obesity make poor outcomes more likely, although participation in workplace wellness programs and preventive screenings has been improving treatment adherence. It also needs to ensure greater effectiveness for poorly situated groups. This is how hypertension is managed in various parts of the world, emphasizing the diversified challenges of its existence and the need for different interventions suitable for multiple countries. It emphasises the convolutions and multilevel orientations towards epidemic hypertension and creates an urgent need for context-specific strategies. Interventions, whether public health campaigns, new technologies, or community-based programs, require a coordinated effort to reduce the hypertension burden globally by healthcare systems, governments, and communities (6).

Hypertension significantly damages almost every aspect of the cardiovascular system, and it exerts its most direct effect on the left ventricle, which is responsible for pumping oxygenated blood throughout the body. Chronically increased blood pressure, in particular, causes pressure overload on LV, resulting in LV remodeling to structural changes and those that are functional (7). These consist of LVH, where the walls of the ventricles become thicker, and diastolic dysfunction, where relaxation and filling during a diastolic phase are impaired. If left untreated, these progress into heart failure and considerably raise disease and deadth as well as the quality of life. Hypertensive heart diseases have become, globally, a heavy burden on healthcare systems. For example, in the United Kingdom, almost a fourth of all heart failure cases can be attributed to hypertensive heart failure. In the same way, most cases of ischemic heart disease and stroke are associated with undiagnosed hypertension in South Asia. Thus, early diagnosis and effective intervention are important to avoid such consequences and related economic and health-related burden (8).

Echocardiography is a direct non-invasive imaging modality of cardiac involvement due to hypertension associated with the diagnosis and management. It provides real-time, direct visualization of the heart and its structural and functional abnormalities. Important

parameters include LV mass, wall thickness, EF (ejection fraction), and diastolic function indices such as the E/A ratio and E/e ratio. All these metrics are indispensable for detecting subclinical cardiac changes and providing timely intervention opportunities. Likewise, echocardiography is versatile enough to accommodate use in every health setting. It is predominantly featured in high-income countries when

assessing therapy-related efficacy and disease course. It is mostly used in LMICs as a cost-effective and non-invasive investigation tool. Case Reports from Rwanda and India demonstrate how portable echocardiography devices have changed access to care for this hypertensive population in resource-constrained environments (9). The study aims to assess and compare the prevalence and severity of LVH in patients with controlled and uncontrolled hypertension using echocardiographic measurements and to evaluate the presence and degree of left ventricular diastolic dysfunction in patients with controlled versus uncontrolled hypertension through echocardiographic parameters such as E/A ratio and E/e ratio and also to determine the differences in LVEF between patients with controlled and uncontrolled hypertension to understand the impact of blood pressure control on cardiac systolic function.

MATERIALS AND METHODS

Study Design, setting, and duration

This is a comparative cross-sectional study that compared and evaluated the echocardiographic findings from patients with controlled and uncontrolled hypertension on the left ventricle. The study was done in Peshawar Institute of Cardiology (PIC), Peshawar Pakistan August 2024 to December 2024.

Population, sample size, and selection of study participants

The population comprised patients diagnosed with hypertension from the Peshawar Institute of Cardiology, Peshawar, Pakistan, attending the cardiology department (out patients and inpatient wards) using convenience sampling. The participants were classified into two groups based on their blood pressure control status, namely controlled hypertension (mean SBP <140 mm Hg and DBP <90 mm Hg) and uncontrolled hypertension (mean SBP ≥140 mm Hg and/or DBP ≥90 mm Hg). Inclusion ctitria was diagnosed hypertensive patients (aged ≥18 years) for at least one year and categorized into controlled or uncontrolled hypertension based on recent medical records. While Patients with valvular heart disease, congenital heart disease, or cardiomyopathy or with a history of MI or stroke within the past six months were excluded.

Pregnant women and patients having poor echocardiographic windows and chronic illnesses affecting cardiac function, such as chronic kidney disease or COPD were also excluded.

Ethical consideration Privacy and Confidentiality

The present research study conformed to the world's most rigorous ethical standards for safeguarding all participants during the research process. Ethical approval for the study was obtained from the Institutional Review Board (IRB) of the Peshawar Institute of Cardiology, Peshawar, and from Ethical board of the Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan.

Participants who decided to participate were asked to sign a written informed consent form, making it clear they could withdraw without repercussions. Collected data through the questionnaire was stored anonymously and securely away from unauthorized access. The identity and information of the participants were kept away from the research and were not published in the process of reporting findings.

Data Collection

Echocardiographic Evaluation

Comprehensive echocardiographic evaluation was performed on each subject to assess left ventricular structure and function. Echocardiographic measurements were done by trained cardiologists/Echocardiographer using routine techniques before the designated echocardiography laboratory of the Peshawar Institute of Cardiology. The key parameters to be assessed included:

Left Ventricular Dimensions: End-diastolic and end-systolic dimensions were measured to evaluate chamber size.

Wall Thickness: Interventricular septal and posterior wall thickness was measured to assess structural changes indicative of left ventricular hypertrophy (LVH).

Ejection Fraction (EF): LVEF was calculated using Simpson's biplane method to assess systolic function. Both groups of controlled and uncontrolled hypertension patients had their echocardiographic data amassed, and this was compared with the structural and functional characteristics of the LV.

Blood Pressure Measurement

Blood pressure (BP) readings were obtained using a calibrated digital sphygmomanometer to ensure accuracy and reliability. For each participant: Three BP measurements were taken at 5-minute intervals. Participants were seated and rested for at least 5 minutes before the first measurement. An average of the three readings were calculated to determine the participant's mean BP It is designed to reduce variability and classify the participants efficaciously into the controlled and uncontrolled hypertension groups. Echocardiographic and blood pressure data were used to explore the relationship between the status of BP control and changes in their left ventricles.

Data Analysis

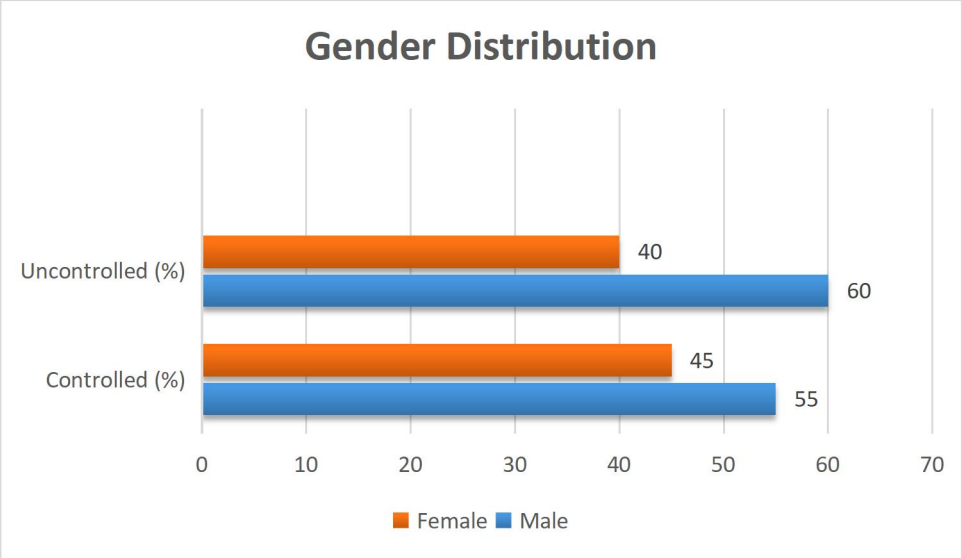
Data were analyzed using SPSS (version 25.0) and GraphPad Prism software. Descriptive statistics were used to summarize the demographic and clinical characteristics of the participants. Continuous variables were presented in mean±standard deviation and categorical variables were expressed as frequencies and percentages, Applicable tests were applied and p-value of <0.05 was considered statistically significant.

RESULTS

Demographics and Clinical Profiles

Gender distribution of participants often provides valuable information on the prevalence and management of hypertension in both controlled and uncontrolled groups. Figure 1 shows apparent predominance of males, which is more evident in the uncontrolled group, suggests possible gender differences in hypertension outcomes or treatment adherence. These findings should now suggest further studies on the effects of those differences in gender-specific factors on hypertension control.

Figure 1: Gender Distribution in Controlled and Uncontrolled Hypertension Groups



The mean age for controlled hypertension was 50.3±7.8 years, whereas that for uncontrolled group members was 52.1±8.5 years. This proceeding shows that with increasing age, it is becoming difficult

for an individual to manage his blood pressure because older individuals might be complicated by physiological alterations and comorbidities, making managing such individuals very difficult. This necessitates even age-related adjustment of hypertensive management processes toward more optimal outcomes for elderly patients.

Clinical Characteristics

The clinical profile of the participants gives an overview of the differences between controlled and uncontrolled medications in terms of the history and control of BP and adherence to antihypertensive drugs. The major clinical characteristics of the two groups are summarized in Table 1. Uncontrolled participants had a longer mean duration of hypertension (10.1±4.5 years) than the controlled group (8.5±3.2 years), suggesting that perhaps prolonged hypertension contributes to complete blood pressure management. Mean systolic blood pressure was considerably raised in the uncontrolled group (148±10 mmHg) than in the controlled group (132±6 mmHg). Likewise, the diastolic blood pressure (DBP) increased over the uncontrolled group, which measured 96±8 mmHg, compared to the controlled group, which measured 85 ± 5 mmHg, pointing to a mismatch between the two studied groups in blood pressure control. A 100% adherence to antihypertensive medication was observed in the controlled group, while only 90% was observed in the uncontrolled group. Such differences accentuate the critical role that consistent adherence to the medication plays in both achieving as well as sustaining effective control of hypertension.

Table 1: Comparison of Clinical Characteristics Between Controlled and Uncontrolled Hypertension Groups

Clinical Characteristic	Controlled Hypertension	Uncontrolled Hypertension
Duration of Hypertension	8.5 ± 3.2 years	10.1 ± 4.5 years
Mean Systolic Blood Pressure (SBP)	132 ± 6 mmHg	148 ± 10 mmHg
Mean Diastolic Blood Pressure (DBP)	85 ± 5 mmHg	96 ± 8 mmHg
Antihypertensive Medication Adherence	100% on pharmacological treatment	90% on pharmacological treatment

Echocardiographic Findings

Prevalence of Left Ventricular Hypertrophy (LVH)

LVH must be considered in the structural dimension of the impact of hypertension on the heart. Table 2 shows the prevalence of LVH and the mean left ventricular mass index (LVMI) regarding the controlled and uncontrolled Hypertension groups. An unchecked group had a significantly higher prevalence of LVH (70%) than the control group (40%). This highlights the negative effect of poorly managed hypertension on the remodelling of the heart. The prolonged duration of high blood pressure for an uncontrolled group most likely causes increased myocardial mass because they have to assume the workload necessary to overcome increased vascular resistance. The analysis of the average LVMI supports this notion. The participants in the uncontrolled group had an average LVMI of 125±15 g/m², significantly higher than the 95±12 g/m² in the controlled group. This difference indicates progressive hypertrophic changes in response to chronic hypertension.

Table 2: Prevalence of Left Ventricular Hypertrophy in Controlled and Uncontrolled Groups

Echocardiographic Findings	Controlled Hypertension	Uncontrolled Hypertension
LVH Prevalence (% of Group)	40%	70%
Mean LVMI (g/m²)	95 ± 12	125 ± 15

These results reaffirm the role of blood pressure control in attenuating left ventricular hypertrophy and reducing the risk for adverse cardiovascular outcomes such as heart failure and arrhythmias. They highlight the management of hypertension early on in life and maintaining it in control to prevent progressive structural changes in the heart and improve long-term outcomes.

Left Ventricular Mass Index (LVMI)

Left ventricular mass index (LVMI) is an important parameter in heart remodelling due to hypertension. Figure2 depicts the mean LVMI of participants in the controlled and uncontrolled hypertension groups. The mean LVMI was several times higher in the latter group (125±15 g/m²) than in the controlled group (95 ± 12 g/m²). This significant increase in the uncontrolled group indicates greater hypertrophic changes with prolonged manifestations of high blood pressure. This prolonged elevation in vascular resistance is expected to result in myocardial thickening, as the left ventricle has now adapted to its new workload, which includes supplying effective cardiac output.

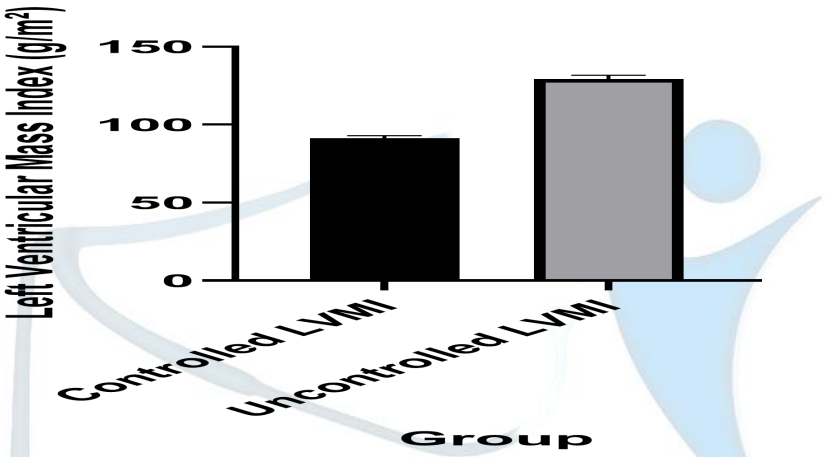


Figure 2: Comparison of Left Ventricular Mass Index (LVMI) Between Controlled and Uncontrolled Hypertension Groups

These considerations indicate that blood pressure management is crucial from the perspective of LVH. In fact, they state that high LVMI is closely linked to many adverse effects, such as heart failure and arrhythmias, which require consideration for early intervention and long-term blood pressure control against progressive remodelling in the heart.

Diastolic Dysfunction Prevalence

Diastolic dysfunction, which prevents the heart from relaxing and filling well during diastole, is a critical outcome of poorly controlled hypertension. This is shown in Figure 4, which depicts the prevalence of diastolic dysfunction in controlled and uncontrolled hypertensives. When compared with controlled hypertensives, the prevalence of uncontrolled diastolic dysfunction was significantly higher (63%) in the unchecked group compared with the controlled ones (37%). This wide differential emphasizes the horrible effect of prolonged uncontrolled hypertension on ventricular relaxation and compliance. High blood pressure raises the left ventricle's stiffness and filling pressures, the defining characteristics of diastolic dysfunction.

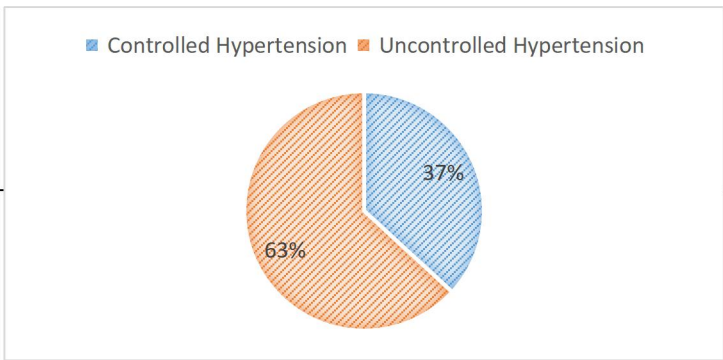


Figure 1.4: Prevalence of Diastolic Dysfunction in Controlled and Uncontrolled Hypertension Groups

Diastolic Function Parameters

The evaluation of diastolic function parameters affords important information on the distinction in left ventricular relaxation and filling pressures between controlled and uncontrolled hypertensive groups with the parameters presented in Table 3.

Table 3: Comparison of Diastolic Function Parameters Between Controlled and Uncontrolled Groups

Echocardiographic Findings	Controlled Hypertension	Uncontrolled Hypertension
E/A Ratio (Mean ± SD)	1.2 ± 0.3	0.9 ± 0.4
E/e' Ratio (Mean ± SD)	12 ± 2	18 ± 3

The lower E/A ratio suggests an increased reliance on late ventricular filling due to atrial contraction caused by stiffening of the left ventricle in uncontrolled hypertension. The E/e, a measure of left ventricular filling pressures, was hugely elevated in an uncontrolled group compared to a controlled group.

Left Ventricular Ejection Fraction (LVEF)

LVEF is one of the most indicative measurements of heart pumping capacity. Table 4 shows both groups maintained LVEF generally within the normal range, but lowered in the uncontrolled group indicating early systolic dysfunction because of long-standing exposure to high blood pressure.

Table 4: Comparison of Left Ventricular Ejection Fraction Between Controlled and Uncontrolled Hypertension Groups

Group	Mean LVEF (% ± SD)
Controlled	60 ± 5
Uncontrolled	55 ± 7

This emphasizes the value of great blood pressure control in protecting LVEF and preventing systolic dysfunction, which may progress to heart failure when not addressed. LVEF should be routinely monitored to allow early detection and intervention in individuals with uncontrolled hypertension.

Systolic Dysfunction Prevalence

The prevalence of systolic dysfunction among the uncontrolled subjects was considerably higher (30%) than that recorded for the controlled group (10%). This suggests the longer-term risks of uncontrolled hypertension about systolic performance.

Statistical Insights

The Left Ventricular Mass Index (LVMI) of controlled and uncontrolled hypertensive patients was subjected to a Mann-Whitney U test, and the results summarized in Table 6 show a highly significant difference in medians ($p < 0.0001$). The median LVMI was significantly higher in uncontrolled versus controlled patients (129.0 g/m² vs 91.0 g/m²), thus indicating significant left ventricular remodeling in participants with poorly controlled hypertension. The U statistic from the test is zero, with the sum of ranks being 5050 and 15050 for controlled and uncontrolled groups, respectively. The difference in medians is found to be 38.0 g/m², equivalent to the value of the Hodges-Lehmann estimate of the median difference. These findings confirm strong associations of uncontrolled hypertension with more pronounced structural alterations in the left ventricle.

This indicates that uncontrolled hypertensive effects are critical in terms of effects on heart structure; it shows that the LVMI of hypertrophy remodelling is much more accentuated. It underlines the

importance of adequate BP control in ameliorating left ventricular hypertrophy and long-term cardiovascular risks. The statistical analysis here warrants early interventions in blood pressure control to prevent untoward cardiac events caused by left ventricular remodelling.

Table 6: Mann-Whitney U Test Results for LVMI Comparison Between Controlled and Uncontrolled Groups

Table Analyzed	**Data 1**
Column B	Uncontrolled LVMI
Vs.	Vs.
Column A	Controlled LVMI
Mann Whitney test	
P value	<0.0001
Exact or approximate P value?	Exact
P value summary	****
Significantly different (P < 0.05)?	Yes
One- or two-tailed P value?	Two-tailed
Sum of ranks in columns A, B	5050, 15050
Mann-Whitney U	0
Difference between medians	
Median of column A	91.00, n=100
Median of column B	129.0, n=100
Difference: Actual	38.00
Difference: Hodges-Lehmann	38.00

DISCUSSION

This research serves to augment the critical influence of BP control in the prevention of cardiac remodelling and the maintenance of heart function. These findings comment on similar observations in previous studies, adding new aspects to the differences in structure and function in controlled and uncontrolled hypertensive patients. LVMI represents a much higher difference of 129.0 g/m² against 91.0 g/m² in the uncontrolled group. This substantiates a significant development of operating hypertrophy at the primary site. Therefore, such results coincided with the findings of Verdecchia et al. (2001), who emphasized a very significant correlation between uncontrolled hypertension and LVH (63). Similarly, Okin et al. (2012) illustrate that efficient blood pressure control reduces LVH and increases patient outcomes, with the same conclusion as this study (64). From this research, a measurement of the flat difference in LVMI furthers finer comprehension of the structural burden due to poorly controlled hypertension.

The diastolic dysfunction indices, such as diminished E/A ratio (0.9 ± 0.4) and augmented E/e ratio (18 ± 3) in the uncontrolled group, illuminate the deleterious effects of prolonged hypertension. This agrees with Devereux et al. (2004), who claimed that poorly controlled blood pressure is linked to diastolic dysfunction and increased filling pressures (65). The results are further complemented by a meta-analysis by Thomopoulos et al. (2020), which showed that aggressive blood pressure control reversed diastolic abnormalities (66). The subtle decline in LVEF in the uncontrolled group (55 ± 7% compared to 60 ± 5% in the controlled group) represents an early indicator of systolic insufficiency. These findings are well recorded in the SPRINT trial (2015), which showed that intense management of hypertension preserves systolic function and decreases the risk of heart failure (67). In addition, Koren et al. (1991) demonstrated that persistent and uncontrolled hypertension hastens the onset of systolic dysfunction and increases the chance of unhealthy cardio outcomes (68). Results from this study also provide more justification for timely intervention to prevent the progression into heart failure.

The implications of these findings are far-reaching in clinical practice; strict blood pressure control is hence necessary to limit structural and functional alteration in the heart. Controlled hypertension was

linked with significantly better echocardiographic outcomes, which further reinforced the value of adherence to medication and lifestyle modification. The uncontrolled group's higher levels of LVMI and prevalence of diastolic dysfunction indicate a more esteemed cardiovascular risk profile. These results are similar with those reported by Okin et al., who stated that inappropriate blood pressure control aggravates cardiac structures and functions (69). The slightly lower medication adherence rate in the uncontrolled group (90% compared to 100% in the controlled group) highlights the importance of patient education and tailored intervention strategies. Chobanian et al. (2003) noted that minor variations in adherence can have cumulative adverse effects on cardiac health (70). Routine echocardiographic checking is a major tool in managing the arterial pressure of patients with poor control over their blood pressure. Early detection of structural changes like LVH and diastolic dysfunction assists clinical men in ordering treatment regimens aimed at the prevention of progression to severe cardiac involvement. Rather, these also establish the comprehensive integration of echocardiographic evaluations into routine care for hypertension.

This study contributes vital knowledge, but it also has some limitations to be considered. The Convenience sampling may have contributed to selection bias and, in turn, may limit the generalization of the findings. Since all participants have been recruited from one cardiology centre, the results do not represent the larger population, specifically those in rural areas or countries lacking resources. Interobserver variability in echocardiographic measurements could also have produced minor variations in results for different parameters. Although a standardized protocol was used, future studies should consider that issue and implement automated or blind evaluation procedures to increase reliability and limit bias.

This cross-sectional design limits the capacity to establish the causal role played by blood pressure control in cardiac outcomes. Thus, longitudinal studies would be needed to assess the temporal development of the structural and functional changes in the hearts of hypertensive populations. It is an eye-opener for further research to close gaps in understanding and managing cardiac remodeling caused by hypertension.

In the future, research efforts should be on longitudinal studies to measure the development of hypertensive cardiac remodeling over time. Such studies will go a long way in delineating how the efficiency of blood pressure control in reducing structural and functional changes chiefly within the LV, represented by LVH and diastolic dysfunction, relates to the passage of time and amount of time before reversal of disruption occurs. For example, Thomopoulos et al. (2020) discussed the possible long-term benefits of intensive antihypertensive treatment without giving a precise time for structural enhancement (10). Longitudinal investigations would also determine whether long-term blood pressure control lowers the risk of asymptomatic remodeling carrying over to the stage of overt heart failure.

The most innovative imaging modalities, such as cardiac magnetic resonance imaging (MRI), provide much greater detail in assessing hypertensive cardiac remodeling. Devereux et al. (2004) claim that MRI is far superior to conventional echocardiography in detecting more subtle changes in the structure and function of the myocardium (11). Advanced imaging technologies should soon enter the study, integrating them to identify early cardiac damage and ensure timely intervention. Also, deformation imaging methods, which measure changing myocardial shapes, could be incorporated into routine evaluation procedures to detect subclinical dysfunction before any considerable structural changes.

A slightly lower adherence rate was found in the uncontrolled group in this study (90% vs. 100%), indicating a clear need for investigation into the barriers to adherence to medication. Studies should look at the socioeconomic factors, the side effects of drugs, and the complexity of the treatment regimens to the impact on adherence. Innovative solutions, including digital health tools, personalized medication plans, and patient education programs, should also be evaluated for effectiveness in improving adherence. For example, mobile applications for reminding, tracking blood pressure, and telehealth counselling would benefit from being tested in different populations (12). In addition, it is necessary to assess how community-based interventions such as peer support groups contribute to long-term adherence.

The management of hypertension may have quite a different effect pattern across age subgroups, especially in those with comorbidities such as diabetes, chronic renal failure, or obesity. Future studies should address differential responses to antihypertensive therapies in this group. For instance, with the intervention involving blood pressure reduction and glycemic control, patients with diabetes may get a better outcome. Studies should also investigate the impact of genetic factors on the efficiency of certain antihypertensive drugs, which would allow the personalization of treatment strategies (13). Understanding these variations will help optimize care and improve outcomes across patient populations.
Hypertension continues to be a major dilemma in public health, majorly in low- and middle-income countries where health care facilities and the technical tools for diagnosing hypertension are limited. Future research should focus on the cost-effective and scalable public health strategies that should be developed or scaled up for hypertension diagnosis and management in low-resource settings. For instance, task-shifting approaches could evaluate the effect of trained community health workers at monitoring blood pressure and providing basic therapy for hypertension disease outcomes (14). An example of policy-focused research would be action to subsidize antihypertensive medications and empower public awareness about hypertension and its complications.
There is a need for behavioral research to evaluate the long-term effects of lifestyle Modifications (diet, exercise, stress management) on cardiac health in hypertensive populations. Stranges et al. (2016) demonstrated that salt reduction, weight management, and regular exercise can significantly improve blood pressure control (15). However, such interventions' long-term feasibility and scalability need further exploration. Future research can study the feasibility of culture-based lifestyle programs across various socio-economic and socio-cultural environments.
There is an immense potential for artificial intelligence and machine learning to transform the management of hypertension. Future studies should focus on using research AI algorithms to analyze echocardiographic data, predict the risk of cardiac remodeling, and personalize treatment configurations. For example, AI-based models may identify patients who are highly susceptible to developing LVH or diastolic dysfunction early interventions (15). These tools could also be used to monitor patients remotely and manage hypertensive patients in an under-resourced setting.

Conclusion

Uncontrolled hypertension was associated with a left ventricular mass index of 129.0 g/m², significantly greater than the controlled value of 91.0 g/m², which is manifest evidence of LVH. Diastolic dysfunction was also more subjective in the uncontrolled group, characterized by a reduced E/A ratio and an elevated E/e' showing impaired left ventricular relaxation associated with increased filling pressures. The systolic function also showed early evidence of compromise in the uncontrolled group, with the mean left ventricular ejection fraction being 55% compared to 60% in the controlled group. The above-mentioned results are clear evidence of the cardiac effects of chronic hypertension and, at the same time, emphasize the protective aspects of constant blood pressure management.
Patients in the uncontrolled group had a longer history of hypertension, higher blood pressure readings, and lower medication adherence, suggesting the multifaceted challenges of managing the condition. Such findings reiterated the importance of early intervention and continuous management in diminishing the long-term risks of developing cardiovascular diseases.

Recommendations

The study findings strongly advocate that routine echocardiographic monitoring be part of the continuum of care in managing individuals with hypertension, particularly among those having poor blood pressure control. When imaging can detect structural and functional changes early, it enables timely plan adjustments. Patients should understand that adherence to medication and lifestyle changes should be complemented by the foundation created, which shows how better management yields significantly improved cardiac outcomes. It is critical to employ personalized treatment strategies based on patients' individual profiles regarding their specific ages, durations of hypertension, and comorbidities; they will

effectively improve care. These strategies will include a multidisciplinary contribution from healthcare providers, i.e. cardiology, nutrition, and behavioral health. This would provide a holistic approach to the medical and behavioural treatment of hypertension.

Future research should take longitudinal studies around the transitional progression of cardiac remodelling and the long-term benefits of continued blood pressure control. Such advanced techniques may include the application of cardiac MRI and much more to obtain clearer insights into how subtle changes occur with hypertension. Studies on digital health interventions such as health mobile applications are likely to bring more efficiency in medication adherence and overall management, especially among high-risk populations. There is a clear need for population-specific studies that will evaluate how effective the strategies for the management of hypertension are for different groups, especially ill patients with other comorbidities such as diabetes or chronic kidney disease. This research will formulate comprehensive and specific guidelines to cater to the needs of heterogeneous populations and achieve better outcomes across a wide patient base. The recommendations will also strengthen the clinical practice worldwide and guide future research to improve cardiovascular health.

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Author's contribution:

1. Author-1 wrote the main manuscript and contributed to the data analysis and data entry and computed tables and charts.
2. Author-2 encouraged author-1 and supervised the overall work until final review. she has discussed and approved the main objectives with author-1.
3. Author-3 has contributed in the final review of the manuscript, supervised closely the author-1 throughout this research.

Author-4 has contributed to the data collection, data entry and discussion.