Echocardiography Findings of Left Ventricular in Patient with Controlled and Uncontrolled Hypertension

SUPERIOR UNIVERSITY

Thesis Submitted to

The Superior University Lahore

In Partial Fulfillment of the

Requirement for the Degree of

Master of Science in Allied Health Sciences

By

FARMAN ULLAH

Roll No. SU91-MSAHW-S23-115

Session 2023-2025

Faculty of Allied Health Sciences

2023-2025 FARAM ULLAH SU91-MSAHW-S23-115 FAHS

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No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Faculty of Allied Health Sciences, The Superior University, Lahore in partial fulfillment of the requirements for the degree of Master of Science in the field of **"Allied Health Sciences"** at The Superior University, Lahore.

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Farman Ullah

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LIST OF ABBREVIATIONS

BP	Blood Pressure
LV	Left Ventricle
LVH	Left Ventricular Hypertrophy
LVEF	Left Ventricular Ejection Fraction
LVMI	Left Ventricular Mass Index
EF	Ejection Fraction
E/A	Early to Atrial filling velocity ratio
E/e'	Early filling velocity to early diastolic mitral annular velocity ratio
HFpEF	Heart Failure with Preserved Ejection Fraction
RAAS	Renin-Angiotensin-Aldosterone System
MRI	Magnetic Resonance Imaging
SNS	Sympathetic Nervous System

ABSTRACT

Introduction

Hypertension is a common malignant disease that adversely affects cardiovascular health, particularly left ventricle function and structure. Under high blood pressure, the left ventricle, which pumps oxygen-rich blood through the body, changes structurally and functionally. These changes have features of left ventricular hypertrophy (LVH) and possible heart failure. Echocardiography, a non-invasive imaging modality, is vital to assess these cardiac changes.

Aim of the study

This study aimed to know 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.

Methodology

The comparative cross-sectional study include 200 hypertensive patients cpmrising 100 controlled hypertension, and 100 uncontrolled hypertensions approached from Peshawar Institute of Cardiology. Convenience sampling methods were used to sample the study participants, and screening for eligibility was based on inclusion and exclusion criteria. Trained echocardiographers performed echocardiographic measurements. Collected data, including demographics about the patient, medical history, and echocardiographic findings. Ethical approval was obtained along with informed consent to conduct the research among all participants.

Results

A statistically significant difference between controlled and uncontrolled hypertensive groups was established. 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 highly significant by statistical means ($p < 0.0001$).

Conclusion

This research study gives deep insights 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

Chapter 1

INTRODUCTION

High Hypertension, more commonly called high blood pressure, is probably the greatest global health challenge. It 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 heart attacks, strokes, heart failure, 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]. Community-based programs are in place that give early detection and awareness to local health workers and have established synergy with resource-limited settings. Japan's high sodium consumption and aging population make It very much at risk for hypertension, and checkups, lifestyle changes, and wellness programs initiated under the "Health Japan 21" initiative have proven to be effective in that cause.

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 the left ventricle, resulting in left ventricular remodeling to structural changes and those that are functional [7]. These consist of left ventricular hypertrophy (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 morbidity and mortality 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 left ventricular mass, wall thickness, 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].

Problem Statement

The most important part of hypertension to one's cardiovascular health is understood in the left ventricle. Unattended high blood pressure is a chronic elevation of systemic blood pressure levels that persists even in the face of maximum treatment and is responsible for subjecting the left ventricle to continuous pressures that induce structural changes such as left ventricular hypertrophy LVH and diastolic dysfunction. The changes thereby increase the chances of suffering heart failure and other negative outcomes. On the other hand, properly controlled or managed hypertension has been shown to reverse or at least alleviate the effects.

Assessing left ventricular function in controlled versus uncontrolled hypertension is clinically significant because it indicates ways through which therapy can be optimized and personalized. Understanding such differences can potentially direct patient engagement towards achieving or maintaining optimal blood pressure, thus impacting the overall outcome. However, despite the clear value of this comparison, it has not been studied sufficiently, especially in heterogeneous populations where control of hypertension is substantially different owing to socioeconomic disparities and differences in health care.

The study intends to fill this gap by examining key echocardiographic parameters, including left ventricular mass and diastolic function indices, to indicate how blood pressure control may impact cardiac health. Data from this study will provide practical evidence that informs clinicians and policy-makers about means of reducing the burden of hypertensive heart disease and improving health outcomes worldwide.

AIM AND OBJECTIVES

1. To assess and compare the prevalence and severity of left ventricular hypertrophy (LVH) in patients with controlled and uncontrolled hypertension using echocardiographic measurements.
2. 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.
3. To determine the differences in left ventricular ejection fraction (LVEF) between patients with controlled and uncontrolled hypertension to understand the impact of blood pressure control on cardiac systolic function.

Chapter 2

LITERATURE REVIEW

Hypertension has an extensive and poignant history beginning in 1733 when Stephen Hales took the first animal blood pressure measurements. This pioneering work laid down the substrates for understanding vascular dynamics and set the research on the basis of hypertension as a physiological phenomenon [10]. The first step was followed by a giant leap in 1896 when Scipione Riva-Rocci invented the sphygmomanometer, which gave a noninvasive means of measuring human blood pressure. The truth is that this device opened a tremendous number of avenues for research and the study of hypertension in large clinical populations, thus revolutionizing clinical practices and research methods [11]. Frederick Mahomed further advanced this discipline in the late 19th century by conceptualizing high hypertension as a separate disease entity with links of high blood pressure-linked vascular damage and cardiovascular diseases. His work marked the first defining moment regarding hypertension as a condition in its own right [12].

The Framingham Heart Study, which started in 1948, was the first real turning point for cardiovascular research [13]. This study was one long longitudinal study to identify risk factors for heart diseases with searing evidence since it showed that even reasonably high levels of hypertension are considered significantly harmful to heart disease and stroke. The study identified hypertension as the very first modifiable risk factor for cardiovascular diseases, which made it more important for an early diagnosis and intervention towards decreasing the burden of complications [14]. Based on this identification, Framingham defined the platforms for public health campaigns and preventive strategies targeting hypertension as a condition.

Moreover, the effects of sustained hypertension were studied, and long-term effects, both inside and outside the body of knowledge, were examined regarding their impact. Known is the very high risk that cardiovascular diseases develop in people who have high pre-hypertensive blood pressure levels later in life. Such discoveries will probably stimulate the will to act before blood pressure reaches such clinical diagnostic thresholds for hypertension [15]. Research conducted on the sympathetic nervous system has demonstrated that this part of the system plays a key role in developing the pathophysiology related to hypertension. Overactivity of sympathetically induced vascular resistance and increased cardiac output were found to be the chief events initiating the mechanism of hypertension. Thus, this research strenuously supports the use of pharmacological therapies, especially beta-blocking agents, for effective targeting of SNS activity [16].

A systematic review of the worldwide burden of hypertension revealed how important this condition is for cardiovascular diseases, especially in low- and middle-income countries. Hypertension contributed to more than half of deaths due to ischemic heart disease and stroke by more than half across the globe, calling for urgent global public health interventions to curb this growing crisis [17]. Furthermore, it is now well accepted that endothelial dysfunction forms a strong basis for hypertensive status; studies have proven that decreased nitric oxide bioavailability and increased oxidative stress affect vascular relaxation. Such findings have driven the evolution of targeted therapies towards restoration of endothelial function and reversal of vascular damage [18].

Such hypertrophic changes occur in the arterial walls by chronic hypertensive stimuli, including the most typical smooth muscle hypertrophy and fibrosis. An increase in arterial stiffness leads to an exaggeration of hypertension through the creation of conditions more favourable disposed of for cardiovascular complications that arise by passion. These irreversible structural changes may be prevented with appropriate intervention early, an aspect that has been highlighted in several studies [19]. Inflammation has been proven to be bad in hypertensive inflammation through the involvement of pro-inflammatory cytokines and shifted immune patterns in vascular injury. Hence, through this work, anti-inflammatory strategies can be a new avenue with great utility in controlling hypertension and its accompanies problems [20].

In recent years, a lot of emphasis has been placed on ethno-medicinal plants and exploring their use as an alternative therapy. The bioactive constituents of medicinal plants identified a perspective of effectively diminishing the risk of cardiovascular diseases associated with hypertension. Thus, these mentioned findings further strengthen the natural approaches to the management of hypertension and control against possible heart diseases [21]. At the same time, numerous studies focused on the complex relationship of obesity, hypertension, and type 2 diabetes, considering the effects of lifestyle as well as metabolic changes in the management of these interrelated entities. For the affected population, it thus becomes imperative to have routine blood pressure and glucose monitoring as this will help in curtailing the risks for cardiovascular diseases [22].

Studies have also examined the longitudinal impact of hypertension on pulmonary health, showing that there is a strong relation between decline in hypertensive pulmonary function over time. This stresses the importance of early intervention in avoiding chronic pulmonary injury [23]. Structural malformations in the cardiovascular system, like coarctation of the aorta, have been implicated in the causative factors of systemic hypertension and accelerated atherosclerosis. This research indicates the need for targeted medical intervention for the identified anomalies to ameliorate associated risks [24].

Oxidative stress has been an important mediator of all forms of cardiovascular injury that present in individuals suffering from high blood pressure. Almost all the recent studies have proven that antioxidants can efficiently decrease oxidative stress markers, thereby opening new possibilities in managing hypertension-associated cardiovascular complications [25]. Probiotics have also emerged as a promising new entry for treating hypertension and metabolic syndrome. Studies have shown that they were effective in modulating gut microbiota toward metabolic health and reduced hypertension-related risks [26]. Partial nephrectomy and radical nephrectomy compare to certain cardiovascular advantages when of renal cancer treatment [27]. These findings specifically emphasize the cardiovascular risks involved in the determination of treatment strategies in renal cancer patients. Living at altitude finds additional physiological challenges, including more hemoglobin, increased arterial stiffness, and a higher prevalence of hypertension. Research has documented in high altitude places that require separate interventions for those specific health risks [28].

These are some technological advances that have changed the management of hypertension. The Mobile-linked monitoring devices serve as important tools in emphasizing self-management and raising awareness of health in hypertensive patients [29]. It improved disease management among patients and outcomes. Further, it has been known that these childhood cancer survivors who had undergone stem cell transplantation frequently develop hypertension and other cardiovascular complications. Studies have longitudinally emphasized the need for monitoring and intervention strategies to bring sabout effective management of these health issues that occur later in life [30].

more than 1.28 billion adults around the globe suffer from hypertension, especially due to developing countries' alarming traction in the same. Public health concerns because of this state could emanate into several propelling forces towards comprehensive prevention, management, and awareness [31]. The Framingham Heart Study was critical in establishing a link between hypertension and cardiovascular disease. The study is an epidemiological giant because it showed that hypertension was the most critical modifiable risk factor for heart disease and stroke. This result has resulted in international approaches aimed at reducing hypertension and its complications through early diagnosis and management [32]. In 2000, Farquharson and Struthers made pioneering studies regarding the renin-angiotensin-aldosterone system (RAAS), noting that this system was a critical regulator of hypertension [33]. Their observation indicated that aberration in the functioning of the RAAS led to vasoconstriction and sodium retention, resulting in a rise in blood pressure. This provided a clear argument in support of the use of RAAS inhibitors like angiotensin-converting enzyme (ACE) inhibitors and angiotensin receptor blockers (ARBs) as useful methods for the treatment of hypertension [34]. These agents, which have thus become part of the standard therapy for hypertension, have shown significant benefits in reducing cardiovascular risks.

Even with the latest therapies available, there is still a large population around the world that remains untreated or poorly managed for hypertension. Studies have cited many barriers to poor access to healthcare, awareness of hypertension, and non-adherence to prescribed therapies. These barriers are common in low-income and developing countries, where health infrastructure and resources are mostly lacking. Narrowing these systemic gaps is imperative for the effective management of global hypertension [35].

The SNS has a major role in the pathophysiology of hypertension. Sympathetic overactivity contributes to vascular resistance and cardiac output, the two major determinants of increased blood pressure. Emerging evidence has also reinforced the case of beta blockers as an important therapeutic approach to control SNS hyperactivity and related cardiovascular hazards due to hypertension [36]. Understanding the mechanistic bases of SNS signalling is thus important for developing targeted therapeutic interventions. Hypertension has resulted from endothelial dysfunction. Such dysfunction is associated with decreased levels of nitric oxide and oxidative stress that impair vascular relaxation and increase arterial stiffness. This physiological derangement increases blood pressure and accelerates the development of cardiovascular complications. The methods employed towards the restoration of endothelial function, like lifestyle changes and calcium channel blockers, have efficaciously succeeded in improving vascular health and curtailing long-term damages [37].

Hypertension has recently been implicated in the major role of inflammation in its development. In particular, increased levels of pro-inflammatory cytokines and immune dysregulation have been shown to contribute to sustaining damage by initial high blood pressure. Studies have shown that anti-inflammatory therapies could work as alternative treatments for hypertension, further paving the way for new guidelines in hypertension management by telling scientists to target inflammation as part of a complete approach to hypertension management [38].

Cardiometabolic syndrome, which is conceived of fatness with diabetes and hypertension, creates some unique problems in managing blood pressure. Evidence has shown that the pathways primarily mediated through leptin in such patients are important modulators of cardiovascular damage. The effective provision of blood pressure management against these risks is critical for future complications [39]. Learning more about the mechanisms underpinning inflammation and fibrosis will highlight roles in disease progression in hypertensive heart disease. Such processes lead to vascular stiffening and remodeling of the heart, for which early intervention is crucial to curtailing this continuum of pathophysiological processes with more beneficial outcomes for patients [40].

Elevated blood pressure, sodium retention, and collateral remodeling forms are typical metabolic derangements in type 2 diabetes. Such pharmacological interventions have proven beneficial in reducing cardiovascular complications within this population [41]. It follows that kidneys function critically to maintain normative systemic blood pressure levels, thereby aggravating hypertension through dysfunctional mechanisms necessitating interventions targeting renal pathways for better blood pressure control [42].

Chronic hypertensive states are deleterious to renal vasculature and cause progressive structural and functional changes over time. Longitudinal investigations have emphasized the need to understand these renal-specific pathophysiological changes to intervene early, including to prevent chronic hypertension progression [43]. In children, most hypertensive conditions are developmental and genetically induced. Early detection and management of such hypertensive conditions would be important in preventing long-term adverse consequences on cardiovascular and renal health in such children [44].

The current trend in research brings to the fore the involvement between the gut and the brain in the pathogenesis of hypertension. For instance, by reducing vascular resistance, hormones such as GLP1 are providing new therapeutic targets to treat blood pressure [45]. In addition, highlighting the molecular cascade involved in hypertension, particularly from the vascular injury to the endothelial changes, further suggests the importance of targeting such molecular pathways for more effective treatment strategies [46].

food habits, high sodium content, and sedentary lifestyles are two significant contributors to hypertension. These two modifiable risk factors signal the importance of global health strategies to mitigate the public health impact of hypertension [47]. Treatment-resistant hypertension stands as one of the greatest challenges in medicine, which has remained fairly elusive to traditional therapies. This calls for innovative approaches toward treatment for unfortunate patients [48]. This suggests that hypertension is indeed a complex and non-linear multifactorial disorder that has genetic, physiological, and lifestyle influences on it. Thus, early intervention, advanced pharmacological therapy, and efforts in public health would effectively manage and reduce the global burden of hypertension.

Echocardiography is thus one of the most important noninvasive imaging techniques, giving an invaluable perspective of cardiac anatomy, function, and hemodynamics. It has been the mainstay of cardiovascular diagnostics because it offers real-time detailed imaging of a cardiac structure and activities [49]. Moreover, progressive echocardiographic techniques like Doppler echocardiography, strain image, and three-dimensional echo have greatly increased the diagnosis capacity. It allows for improved evaluation and management of conditions like heart failure and valvular diseases with decreased left ventricular hypertrophy [50].

Doppler echocardiography is one of the most phenomenal advances in the field [51]. It measures blood flow velocities across the heart valves and provides critical information concerning valvular stenosis, regurgitation, and overall cardiac output. This modality has particularly turned out to be helpful in assessing diastolic function and pulmonary pressures; thus, it has become a pillar in managing heart failure with preserved ejection fraction (HFpEF). The ability of Doppler echocardiography to evaluate left ventricular filling pressures has added precision to the whole diagnostic and therapeutic process [52].

Three-dimensional echocardiography accomplishment in the application of cardiac imaging is yet another major feature. It provides a more accurate measurement of left ventricular volumes and ejection fractions compared with traditional two-dimensional echocardiography [53]. Its use is particularly noticeable in complex ventricular geometries, yielding better information to manage structural heart diseases. This modality has also proved its value in guiding surgical interventions, particularly for mitral valve repair, and has significantly improved procedural outcomes and safety for patients [54].

Strain imaging has become one of the important tools in echocardiography. It assesses the deformation of the myocardium and can detect subclinical myocardial dysfunction at an earlier stage than traditional measures, like ejection fraction. Strain imaging finds prominent application in hypertensive heart disease and chemotherapy-induced cardiomyopathy as it allows continuing intervention during the early stages of the progression of the disease. This modality is the hallmark of what sophisticated imaging could do for better patient outcomes in accurate and timely diagnosis [55].

There was a significant role of echocardiography in assessing left ventricular hypertrophy (LVH) in a patient with hypertension. The left ventricular mass index (LVMI) and relative wall thickness (RWT) are parameters that typically assess the structural effect of hypertension on the heart. These measurements are not only diagnostic but also prognostic, offering assistance in developing different risk stratification and treatment schemes for patients suffering from hypertensive heart disease [56].

Heart failure with preserved ejection fraction (HFpEF) creates its own diagnostic and therapeutic problem, and echocardiography has become central to this aspect. The evaluation, for example, of the E/A ratio coupled with tissue Doppler indices such as E/e' has provided interesting insights into diastolic function and filling pressures within the left ventricle. Such measurements would prove compulsory for differential diagnosis of the underlying causes of HFpEF and tailored therapy for the patient, particularly so in patients whose clinical presentations were divergent [57].

Some specialists even utilize echo for planning procedures such as Transcatheter aortic valve implantation (TAVI) advanced interventional diagnostics practice in which most generalists will not find much use [58]. On the other hand, special populations generally include those in need because the advanced imaging modality would benefit them when it comes to pre-procedural planning, intraoperative assistance, and follow-up stages for those whose patients would be subjected to severe valvular dysfunction at a younger age. Many echo-centered patients can achieve sound procedural results with reduced complications by allowing them to be evaluated and measured in real-time and on a high-accuracy scale [59].

In pediatric settings transforming echocardiography, the introduction of artificial intelligence (AI) has been transformational. Using AI-driven automated analyses, congenital heart defects can be detected much earlier in life, with improved diagnostic accuracy and efficiency. As a result, innovations in the management of these tools have improved clinical workflows and narrowed the margins for error so timely interventions can be made in defenceless pediatric populations [60].

Another advanced technique in this aspect has been employed in differentiating right atrial masses from pseudo masses, referred to as tissue Doppler imaging. This is especially interesting in cases that are very ambiguous and critical since, without accurate diagnosis, major treatment decisions might be dictated. Thus, tissue Doppler imaging becomes a trusted noninvasive alternative to more invasive diagnostics and is therefore regarded essential in clinical cardiology [61].

Combined with echocardiography, wearable cardioverter defibrillators represent a stronghold in heart failure management. With the aid of this technology, thorough identification of “high-risk” patients is achieved for timely preventive interventions regarding arrhythmic events. Thus, these technologies form part of innovative frontiers in personalized cardiac care [62].

Advanced algorithms AI has been increased in echocardiographic imaging through which direct estimation of ventricular pressures and deformation in myocardial is possible. Applications extend to diagnosing and managing complex cardiovascular diseases, especially heart failure and cardiomyopathy. AI-informed insights for improving cardiac imaging capacities in diagnostics are future affairs [63]. It has also been possible for echocardiography to advance a really long way toward diabetic cardiomyopathy. This has become the avenue for detecting early structural and functional changes in the heart that could allow for timely interventions to slow or halt disease progression. The above has emphasized the scope for applying echocardiography in different cardiovascular conditions [64].

Strain imaging has become a significant tool for detecting subclinical cardiotoxicity in chemotherapy patients. This tool allows for earlier detection of myocardial dysfunction early enough for interventions before major cardiac damage occurs. Applications of such kind emphasized the role of echocardiography in preventive cardiology [65]. Yet another advanced echocardiography application is a technique called left ventricular pressure–strain loop. It delivers finer details about the mechanics of the myocardium, especially in patients with heart failure and reduced ejection fraction. It influences the management and treatment plan for patients, with greater precisions [66].

Transthoracic echocardiography is increasingly being used for the evaluation of potential embolic sources among patients with stroke. This form of patient assessment combines cardiovascular and cerebrovascular diagnostics for the management of those patients; this can help improve outcomes for patients who are at risk for recurrent embolic events [67]. In echocardiographic imaging, cutting-edge developments in deep learning are changing the game. New AI-enabled technologies deliver real-time prediction of multi-beat cardiovascular dynamics, advance accuracy in diagnosis, and enable better monitoring of even the most complicated cardiac conditions. These innovations signal pushing further the envelope of what echocardiography can do in modern medicine [68].

Echocardiography, known as heart ultrasound, is still the most important tool for diagnosing cardiovascular diseases. Progressive applications into more sophisticated techniques have further improved the role of echocardiography in clinical and research fields. The recent methods have widened echocardiography's diagnostic and therapeutic horizon [69]. The use of nanobubbles in contrast-enhanced ultrasound is a complete revolution in echocardiographic imaging: it dramatically enhances the ability to visualize microvascular blood flow, thus helping to support a much earlier diagnosis of ischemic heart disease, which can result in an early detection of this abnormality. Such an event would be a breakthrough in the development of cardiovascular diagnostics and preventive care [70].

Artificial intelligence has been woven into the very fabric of echocardiography and has changed the ways of assessing this function of the heart. AI-based algorithms greatly facilitate the interpretation of essential values, like the ejection fraction, dimensions of the cardiac chambers, and strain imaging [71]. These innovations not only augment the effectiveness of parameters but also enhance the accuracy of diagnosis in a rather more obscure realm: where the valve is involved in valvular heart diseases and detailed assessments impact patient outcomes.

Visualization of the heart structures with unparalleled clarity has been possible due to advances in three-dimensional (3D) echocardiography. This has been great in managing structural heart diseases, especially with planning and guidance for procedures such as mitral valve repair. It ensures accurate spatial orientation to increase the safety of the surgical procedure and the patient [72].

Real-time, high-resolution imaging of the intracardiac anatomy has made intracardiac echocardiography extremely useful for interventional cardiology. For example, cardiology may use it for very complicated procedures like closure of patent foramen ovale or atrial septal defect repair. Procedural outcomes are enhanced because detailed visualization is provided to execute with precision [73].

Strain imaging has jettisoned its importance into early detection of myocardial dysfunction, especially in hypertensive heart disease patients or those treated for cardiomyopathy induced by chemotherapy. The test measures the deformation patterns of the myocardial fibres that form a means of detecting clinical dysfunction in the affected organ. Early detection using strain imaging enables prevention strategies and management improvement [74].

Stress echocardiography is another technique that quantifies how the heart reacts to external stressors well. In particular, it can be applied clinically in assessing right ventricular function and evaluating pulmonary artery pressures in pulmonary hypertension. Therefore, this technique would provide a basis for diagnosis and monitoring of disease progress, as well as for making treatment interventions specific [75]. For example, scanning with radiotracers and echocardiography is emerging as a next-generation molecular imaging technique. This approach can demonstrate inflammatory and fibrotic changes in various cardiomyopathies and better understand the pathophysiological mechanisms involved. Further refinement of the methods remains an ongoing research effort for improving cardiovascular diagnostics [76].

Modern echocardiographic modalities, such as strain imaging modalities, are currently deployed to study atrial cardiomyopathy. They identify atrial dysfunction and allow individualized interventions to prevent thromboembolic complications. Such approaches mark precision medicine's role in cardiovascular care [77]. Small transducers and 3D imaging are used to evaluate and follow up children with congenital heart lesions over a long period. The result of these innovations is that outcomes for children with congenital heart disease have improved as a result of earlier and more accurate diagnoses [78].

Hypertension is deemed controlled when blood pressure is maintained lower than 140/90 mmHg through the career of medication and lifestyle alteration [79]. Despite having made giant strides in awareness and treatment, almost 50% of the world's population with hypertension has uncontrolled hypertension. Many factors, including poor treatment adherence, limited healthcare accessibility, and therapeutic inertia, aggravate it. Public health activities that will fill the gap between such treatments and patient compliance will be focused on the above challenges.

Poorly controlled hypertension usually afflicts most low- and middle-income areas of less than 20% of their patients. Several factors contribute to such an endemic nature, including infrastructural deficiencies in health care, exorbitant costs of medication, and weak public awareness campaigns. These findings offer ample justification to call for systemic improvements in screening, treatment and continuation of care in addressing the disparities in healthcare delivery [80].

The major cause of high blood pressure that fails to be controlled is the nonadherence of patients to prescribed antihypertensive medications. High levels of nonadherence are related to the high prevalence of side effects, the multiplicity of treatment regimens, and socioeconomic barriers. Inadequate intensification or inappropriate readjustments from the prescribers have been termed therapeutic inertia. This challenge can be overcome with proper education for patients and training for clinicians, which improves management of hypertension [81].

Resistant Hypertension is one of the severest forms of hypertension as it remains uncontrolled even by more than three antihypertensive drugs; diuretics among them [82]. Studies have attributed secondary causes such as hyperaldosteronism or renal artery stenosis as important factors in the existence of this condition. The Real Cause Addressed only involves pharmacological intervention and lifestyle changes for effective management of underlying pathophysiological causes.

Renal Denervation is a newly developed therapy for resistant hypertension. This therapy has reduced the activity of sympathetic nerves in the kidneys and has a modest effect on lowering blood pressure in select groups of patients. However, further studies have produced mixed results, indicating that research should be continued before one understands its therapeutic effectiveness or starts to filter suitable patients [83].

The worldwide burden of uncontrolled hypertension is aggravated by the weight on underserviced populations, especially in lower-income or other more reliant areas. Accessibility to health services and prevention has been indicated to be one of the most significant contributing factors. To bridge such disparities, it is essential to set up fair health policies and targeted interventions for improved access to care [84]. Lifestyle modifications have all proven very effective in the management of uncontrolled hypertension. For example, reduced salt intake, weight loss, and regular physical activity are potential modifiers of blood pressure control. Studies have shown that lifestyle counseling in routine care for hypertensive patients improves the outcome [85]. Patients suffering from uncontrolled hypertension often need a combination of antihypertensive therapies. The use of different classes of drugs is intended to optimize efficacy and reduce failure rates. Fixed-dose combination therapies are particularly effective in simplifying regimens, promoting patient adherence, and further improving control of blood pressure [86].

Therapeutic inertia is a poorly understood element of hypertension management. Clinicians often do not modify regimens in patients with unsatisfactory blood pressure control, leaving these patients at risk for complications. This indicates a need for learning more about how clinician behaviours impact hypertension outcomes and forms the basis for studies investigating interventions to overcome therapeutic inertia [87].

The renal denervation for treatment against resistant hypertension indicated variability in the results between studies [88]. They included indications from the absence of large-scale trials necessary for long-term benefit and safety characterization, stating that further research is still warranted to determine efficacy for general applicability.

The early detection of myocardial dysfunction among hypertensive patients by strain imaging. They reported limited use of the technique because of cost and accessibility issues [89]. This gap indicates the need to investigate the incorporation of advanced diagnostics into routine care, particularly in resource-poor settings.

Lifestyle modifications such as salt restriction and the uptake of physical activity can help manage hypertension [90]. However, they pointed out that the current evidence lacks information on maintaining such interventions in disadvantaged communities.

For this reason, future exploration in more realistic contexts is still warranted. The global disparities in hypertension management claimed a lack of evidence for culturally tailored interventions that improve adherence in diverse populations [91]. They hold that research needs to be conducted in culturally sensitive ways to enhance treatment adherence and reduce differences. Current research gaps, such as disparities in care, therapeutic inertia, and poor adoption of advanced diagnostics and treatment tools, substantiate the need to conduct this study. Closing such gaps is important as it will allow empirical evidence to form the basis for targeted strategies that would otherwise be advocated for hypertensive control and outcome improvement. Thus, the study aims to tap into such gaps comprehensively and contribute to the world's great effort in hypertension control [92]. There is still much yet to learn concerning one of the most relevant areas of study: the differential effects between controlled and uncontrolled hypertension on the structure and function of the left ventricle.

Evidence establishes that controlling blood pressure has important beneficial effects on cardiovascular outcomes; however, different populations and treatment regimens cause variability in findings [93]. There was much contention around what should be the ideal blood pressure targets demonstrated in recent trials. Although intensive lowering shows considerable cardiovascular benefits, it is plagued by the risk of hypotension and associated comorbidities that complicate universal treatment recommendations [94]. This study intends to fill such gaps by comparing echocardiographic parameters among patients with controlled and uncontrolled hypertension, thereby providing important data for clinical practice and future research.

Chapter 3

METHODOLOGY

3.1. Research Design

This comparative cross-sectional study compared and evaluated the echocardiographic findings from patients with controlled and uncontrolled hypertension on the left ventricle. In this design, it would be possible to compare cardiac structural and functional differences among the above two groups at a certain time and understand how blood pressure control influences the remodeling of the left ventricle. At this time, substantial differences in echocardiographic parameters can be emphasized to realise value changes that significantly evolve hypertensive hearts.

3.2. Clinical Settings

The population comprised patients diagnosed with hypertension from the Peshawar Institute of Cardiology, Peshawar, Pakistan, attending the cardiology department. 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).

3.3. Sample Size: 200 hypertensive patients (100 controlled hypertension, and 100 uncontrolled hypertensions).

3.4. Sampling Technique: Convenience sampling

3.5. Duration of study: Approximately six months

3.6. Selection criteria

3.6.1. Inclusion Criteria

- Patients aged 18 years and above.
- Diagnosed with hypertension for at least one year.
- Categorized into controlled or uncontrolled hypertension based on recent medical records.
- Willing to provide informed consent for participation.

3.6.2. Exclusion Criteria

- Patients with valvular heart disease, congenital heart disease, or cardiomyopathy.
- Patients with a history of myocardial infarction or stroke within the past

six months.

- Pregnant women.
- Patients unable to undergo echocardiographic evaluation due to technical reasons or poor echocardiographic windows.
- Patients with chronic illnesses affecting cardiac function, such as chronic kidney disease or chronic obstructive pulmonary disease.

3.7. Ethical Consideration

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, Pakistan. The same were carried out per the principles of the Declaration of Helsinki.

3.8. Data Collection Procedure

An exhaustive echocardiographic evaluation was performed on each subject to assess left ventricular structure and function. Echocardiographic measurements were done by trained cardiologists 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):** The left ventricular ejection fraction 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 left ventricle.

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.

3.9. Data Analysis

Data were analyzed using Statistical Package for the Social Sciences (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 expressed as mean ± standard deviation (SD) and compared using the independent t-test. Categorical variables were expressed as frequencies and percentages and compared using the chi-square test. Multivariate logistic regression analyses were performed to identify independent left ventricular hypertrophy and dysfunction predictors. A p-value of <0.05 was considered statistically significant.

Chapter 4

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 describes the gender composition of the study population. Among participants with controlled hypertension, about 55% were males and 45% females. For the uncontrolled group, the percentage of males increased by 5%, resulting in 60% of respondents being males, while females are only 40%. This 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.

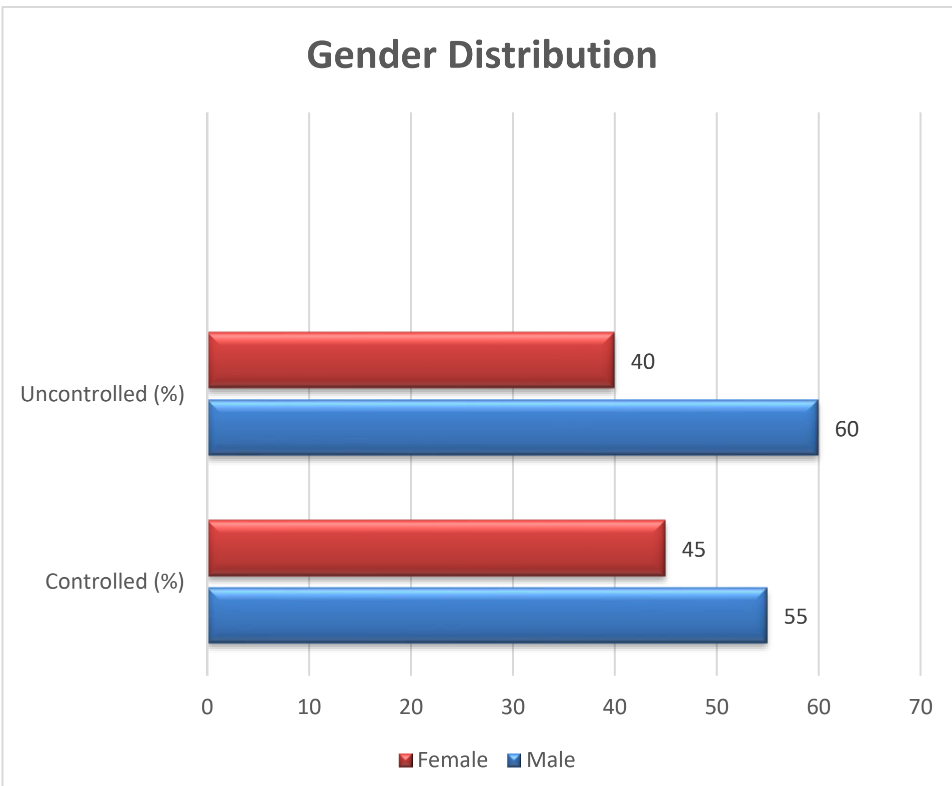

Figure 4.1 Gender Distribution in Controlled and Uncontrolled Hypertension Groups

Age Distribution

Disparities in the demographic distribution among subjects according to their age now sought to bring out its possible effect on hypertension management regarding the controlled and uncontrolled groups. The mean Age of Participants in Both Groups is Illustrated in Figure 2. 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.

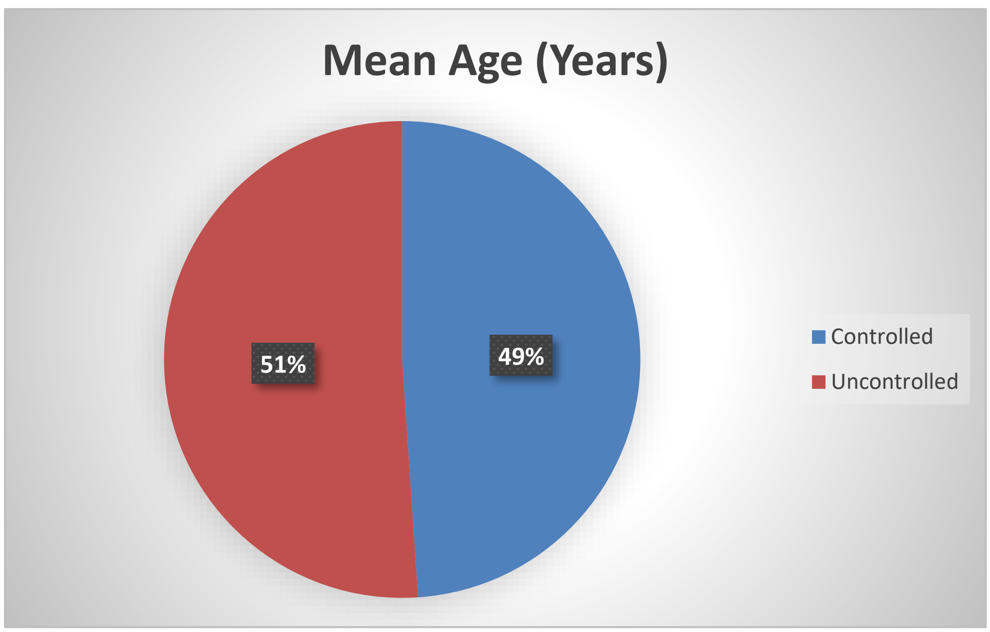

Figure 4.2 Mean Age Distribution Between Controlled and Uncontrolled Hypertension Groups

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 blood pressure 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 higher 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 4.1 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

The timely and sustained interventions needed to improve blood pressure management were highlighted by these findings, particularly in people with a long-standing history of hypertension as well as those who were poorly compliant with medication.

Echocardiographic Findings

Prevalence of Left Ventricular Hypertrophy (LVH)

Left ventricular hypertrophy 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 4.2 Prevalence of Left Ventricular Hypertrophy in Controlled and Uncontrolled Groups

Echocardiographic Findings	Controlled Hypertension	Uncontrolled Hypertension
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. Figure 3 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.

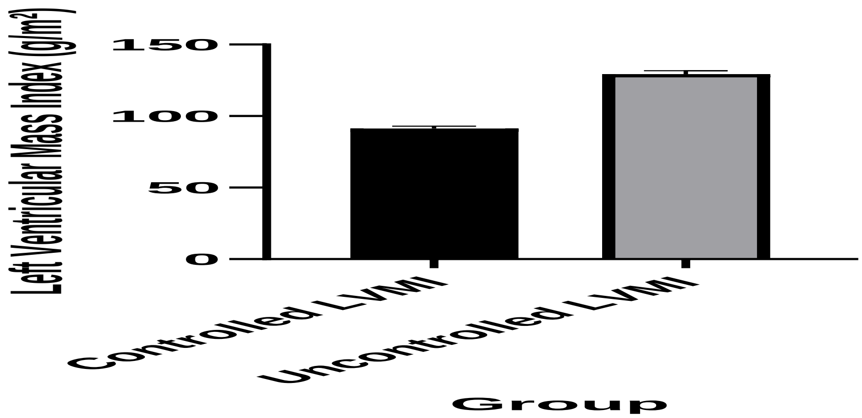

Figure 4.3 Comparison of Left Ventricular Mass Index (LVMI) Between Controlled and Uncontrolled Hypertension Groups

These considerations indicate that blood pressure management is crucial from the perspective of left ventricular hypertrophy (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.

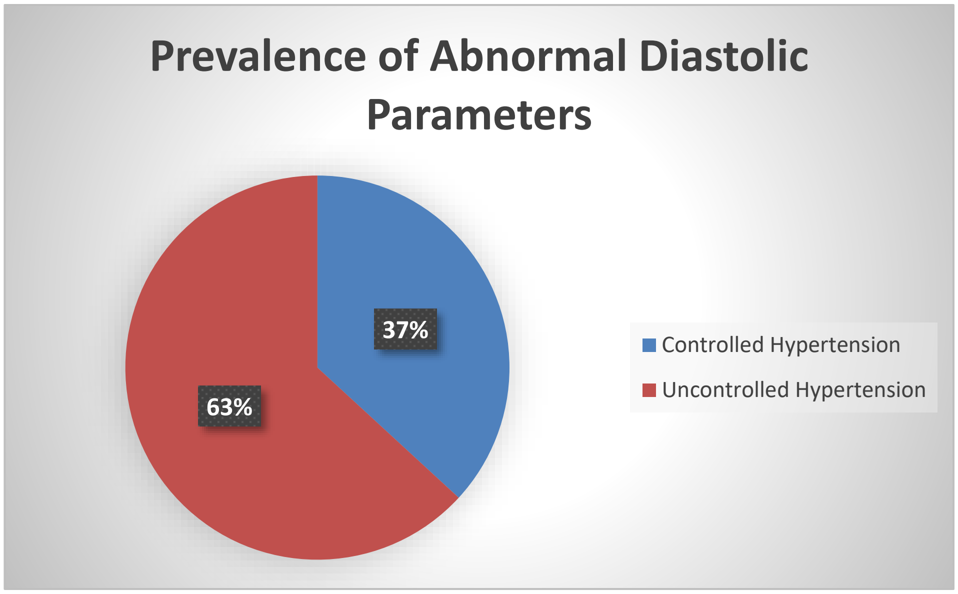

Figure 4.4 Prevalence of Diastolic Dysfunction in Controlled and Uncontrolled Hypertension Groups

These findings highlight the absolute necessity of efficient management of hypertension for lowering the probability of diastolic dysfunction. It may facilitate the preservation of ventricular compliance and decrease the chances of progressing to heart failure with preserved ejection fraction (HFpEF) through early intervention towards blood pressure control.

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. The E/A ratio, which indicates the early (E) versus late (A) filling velocities into the ventricles, was markedly lower in the uncontrolled group (0.9 ± 0.4) than in the controlled group (1.2 ± 0.3).

Table 4.3 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

This reduction indicates impaired left ventricular relaxation in the uncontrolled group- a hallmark of diastolic dysfunction (Figure 5). 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. Figure 6 bar charts show a statistical comparison of E/A ratio values between the two groups. The unchecked group shows a lower ratio and thus reflects impaired diastolic filling and reduced ventricular relaxation.

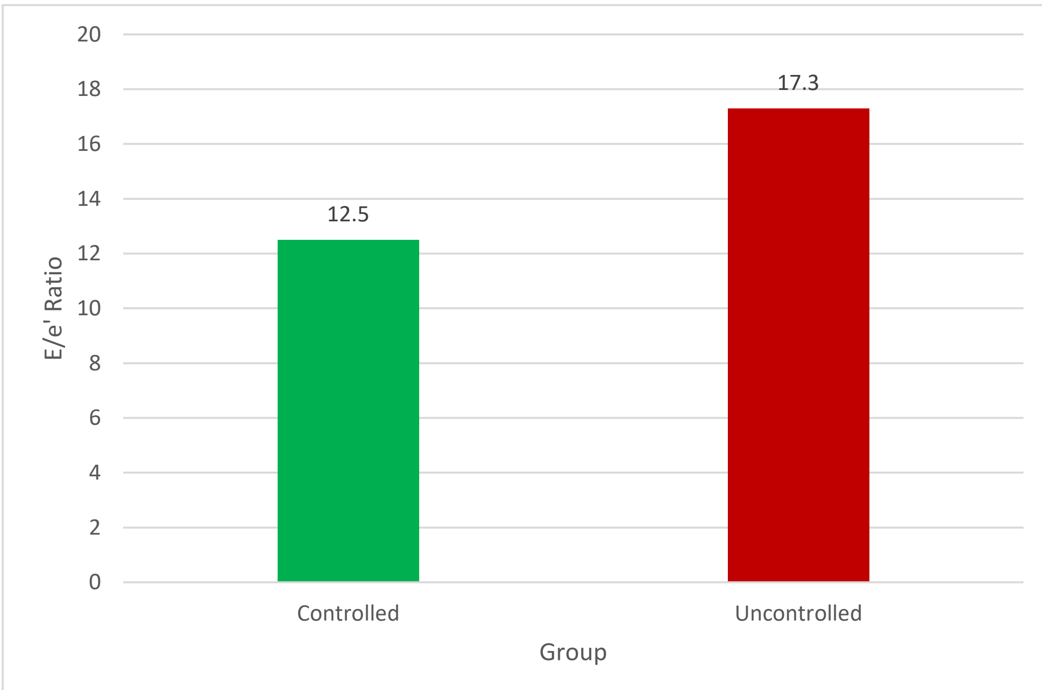

Figure 4.5 Comparison of E/e Ratio Between Controlled and Uncontrolled Hypertension Groups

The E/e, a measure of left ventricular filling pressures, was hugely elevated in an uncontrolled group (18 ± 3) compared to a controlled group (12 ± 2). Increased left ventricular stiffness and filling pressures are evident in the uncontrolled group, indicative of worsening diastolic function (Figure 6). Figure 7: The bar chart compares the E/e ratio, in which uncontrolled groups revealed substantially higher values. The ratio has further highlighted the adverse impact of that blood pressure on ventricular compliance.

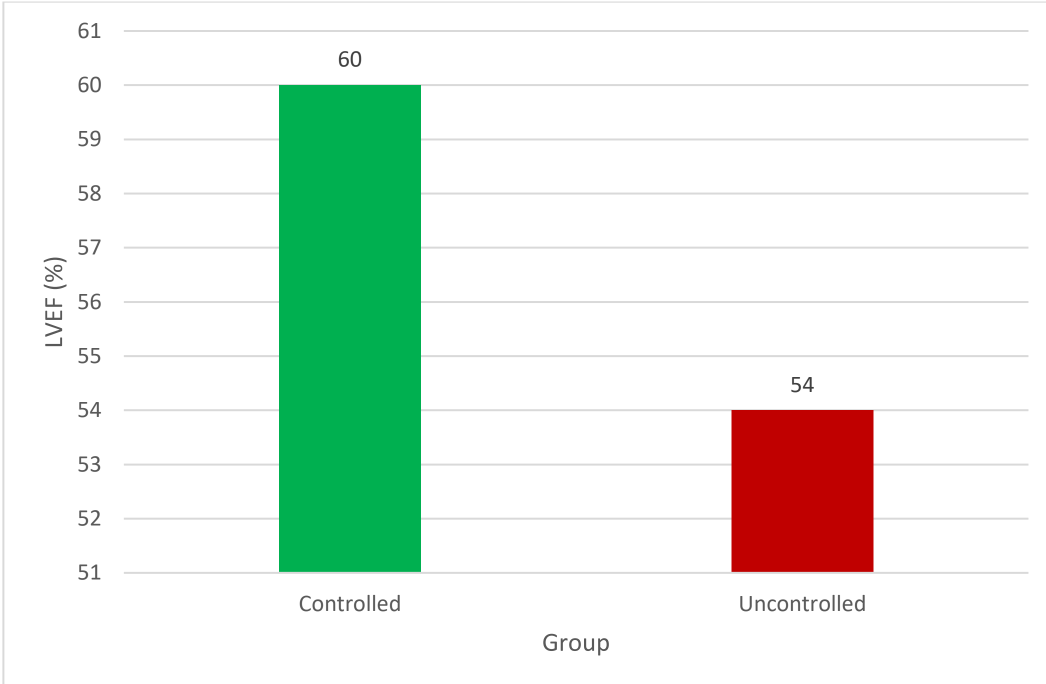

Figure 4.6 Comparison of Left Ventricular Ejection Fraction (LVEF) Between Controlled and Uncontrolled

Left Ventricular Ejection Fraction (LVEF)

LVEF is one of the most indicative measurements of heart pumping capacity. Table 4 compares mean LVEF between the controlled and uncontrolled hypertensives: margin LVEF is significantly lower in the unchecked group (55 ± 7%) than in the controlled group (60 ± 5%). Both groups maintained LVEF generally within the normal range, but lowered in the uncontrolled group indicates early systolic dysfunction because of long-standing exposure to high blood pressure.

Table 4.4 Comparison of Left Ventricular Ejection Fraction (LVEF) Between Controlled and Uncontrolled Hypertension Groups

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

This difference is shown in Figure 7, which indicates that the controlled group has preserved systolic function. A lower LVEF again shows the currently evident early detrimental influence that poorly managed hypertension inflicts on cardiac function in the uncontrolled group.

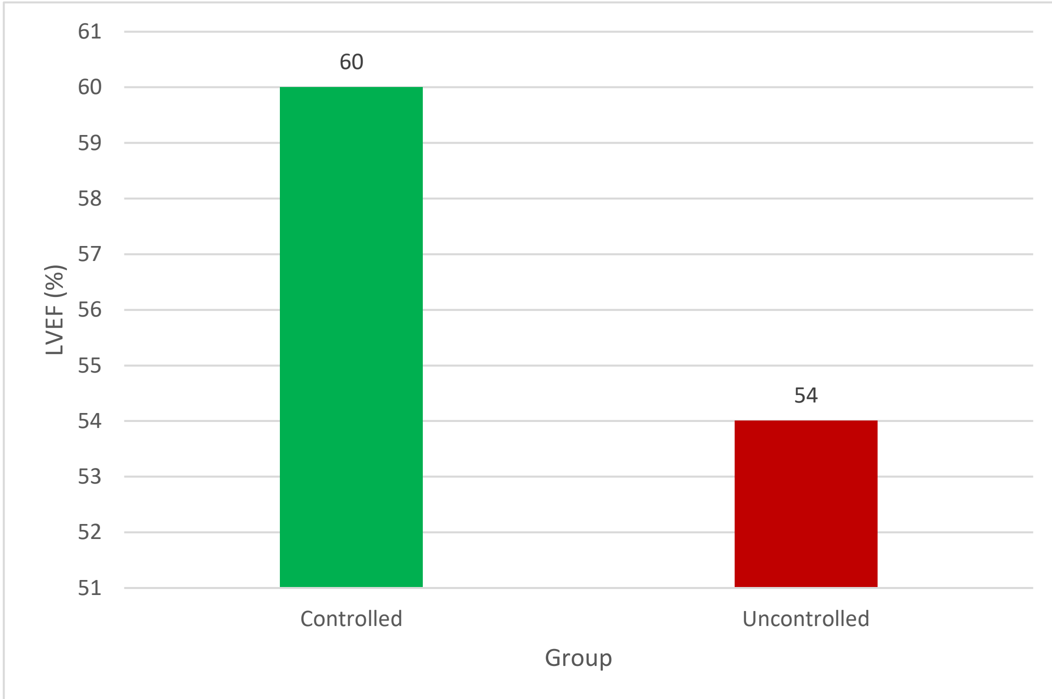

Figure 4.7 Comparison of LVEF Between Controlled and Uncontrolled Hypertension Groups

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

According to evidence provided in Table 5, 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.

Table 4.5 Prevalence of Systolic Dysfunction in Controlled and Uncontrolled Hypertension Groups

Group	**Prevalence (%)**
Controlled	10%
Uncontrolled	30%

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/m^2 vs 91.0 g/m^2), 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/m^2, 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.

Table 4.6 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

Interpretation of Data

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 blood pressure 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.

Chapter 5

DISCUSSION

This research serves to augment the critical influence of blood pressure control in the prevention of cardiac remodelling and the maintenance of cardiac 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. The left ventricular mass index (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 left ventricular hypertrophy (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 impaired diastolic function 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 left ventricular ejection fraction (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

Further 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 changes in the heart. Controlled hypertension was associated 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 consistent 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. The study suggests future avenues of inquiry for investigators, building on this work toward more efficacious clinical and public health interventions.

In the future, research efforts should be directed at 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 left ventricle, represented by left ventricular hypertrophy (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. [95]. 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 [96]. 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 [97]. 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 [98]. 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 [99]. 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 behavioural 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 [100]. 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 [101]. These tools could also be used to monitor patients remotely and manage hypertensive patients in an under-resourced setting.

CONCLUSION

Such a study emphasizes the overwhelming impact that is managing blood pressure effectively can have on cardiac remodelling and the preservation of heart function. Uncontrolled hypertension was associated with a left ventricular mass index of 129.0 g/m^2, significantly greater than the controlled value of 91.0 g/m^2, which is manifest evidence of left ventricular hypertrophy. 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.

Limitations

The study is correctional design and data are obtained from a single center hence the generalizability of result are reduced.

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, namely 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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APPENDICES

ENGLISH CONSENT FORM

The study you are about to participate is a randomized control trial survey titled as;

"Echocardiography findings of left ventricular in patient with controlled and uncontrolled hypertension"

The study has no potential harm to participants. All data collected from you will be coded in order to protect your identity, and should not be disclosed to anyone. Following the study there will be no way to connect your name with your data. Your answers to the questions will not affect the quality of education given to you. Any additional information about the study results will be provided to you at its conclusion, upon your request.

You are free to withdraw from the study at any time. You agree to participate, indicating that you have read and understood the nature of the study, and that all your inquiries concerning the activities have been answered to your satisfaction.

NAME ________________________ SIGNATURE___________________

DATE___________________________

URDU CONSENT FORM

میں ____________ نے اپنی اس تحقیق**(FARMAN ULLAH)محترمہ** تصدیق کرتا/ کرتی ہوں کہ

“Echocardiography findings of left ventricular in patient with controlled and uncontrolled hypertension”

کے متعلق بتا دیا ہے۔ مجھے اس تحقیق کی نوعیت، مقاصد، **(DR. CHANDA NASEEM)** .زیرنگرانی
احداف، توقعات، فوائد اور خطرات کے متعلق ، ۔ساری معلومات فراہم کر دی گئی ہیں
اس تحقیق کے دوران ساری معلومات صیغۂ راز میں رہیں گی اور مریض کا نام اور دیگر معلومات صرف
تحقیق کے لیے استعمال ہوں گی۔مجھے یہ بھی بتا دیا گیا ہے کہ میں اس تحقیق سے متعلقہ ہر قسم کے
سوال پوچھنے کا مجاز ہوں اور یہ تحقیق صرف ایک شخص ک مفاد میں نہیں ہے بلکہ بحسثیت
مجموعی انسانیت کا مفاد اس سے وابسطہ ہے۔ تمام تفصیلات جاننے کے بعد یس تحقیق میں شامل ہونے
یا نہ ہونے پر کسی کا قائل نہیں ہوں۔ اس تحقیق سے کسی بھی وقت علیحدہ ہونے پر مجھ پر کوئی
پابندی نہیں ہو گی۔ میں بذاتِ خود بقائمی حوش و حواس
۔اور رضا مندی سے اس تحقیقاتی عمل میں شامل ہوتی/ ہوتا ہوں

دستخط محقق --------------------------

دستخط شرکت کار --------------------------

تاریخ --------------------------

DEMOGRAPHICS FORM & QUESTIONNAIRES

PERMISSION LETTER

ETHICS COMMITTEE LETTER

PLAGIARISM REPORT