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Original Article

A Cross-Sectional Observational Study on Echocardiographic Assessment of Right Heart Function Across Various Stages of Hypertension

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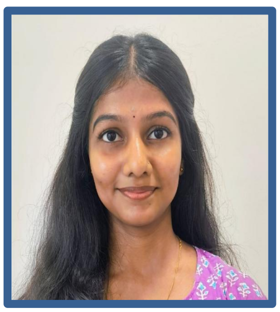

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ABSTRACT

Background: Hypertension is a major global health problem and an important risk factor for cardiovascular morbidity and mortality. While its effects on left heart function are well established, emerging evidence suggests significant involvement of the right heart. This study aimed to assess right heart morphology and function using echocardiography in patients with different stages of hypertension and to identify the most accurate parameter for detecting right ventricular dysfunction.

Methods: A cross-sectional observational study was conducted among 50 hypertensive patients attending the cardiology outpatient department, emergency department, and intensive care unit at Chettinad Super Speciality Hospital. Right heart function was assessed using echocardiographic parameters and correlated with stages of hypertension.

Results: Among the 50 patients, 29 (58%) were males and 21 (42%) were females, with a mean age ranging from 20–80 years. Echocardiographic assessment showed no significant differences in hemodynamic parameters, including RAP, PASP, PAEDP, MPAP, and RVSP measured by TAPSE. However, Doppler-derived tricuspid valve diastolic parameters (E/A ratio and deceleration time) demonstrated better accuracy in identifying right ventricular dysfunction. Stage 2 and Stage 3 hypertension showed greater association with right heart dysfunction.

Conclusion: Right ventricular diastolic dysfunction appears to be an early and reliable marker of right heart involvement in hypertension, particularly in advanced stages.

Keywords: Echocardiography; Right Ventricular Dysfunction; Cardiac Remodeling.

Introduction:

Hypertension is one of the most prevalent cardiovascular disorders and a major modifiable risk factor for cardiovascular morbidity and mortality worldwide. It is characterized by persistent elevation of arterial blood pressure, resulting in increased pressure within the systemic arterial circulation [1]. Blood pressure is measured in millimetres of mercury (mmHg) and is represented by two values: systolic blood pressure (SBP), which reflects arterial pressure during ventricular contraction, and diastolic blood pressure (DBP), which reflects arterial pressure during ventricular relaxation. Hypertension is clinically diagnosed when systolic blood pressure is ≥140 mmHg and/or diastolic blood pressure is ≥90 mmHg on repeated measurements [2].

Blood pressure is determined by the interaction between cardiac output and systemic vascular resistance, expressed as: BP=CO×SVRBP = CO \times SVRBP=CO×SVR, where cardiac output refers to the volume of blood pumped by the heart per minute, and systemic vascular resistance represents the resistance offered by peripheral blood vessels to blood flow. An increase in either or both of these factors contributes to the development of hypertension. Chronic elevation of blood pressure results in vascular remodeling, increased arterial stiffness, and progressive damage to target organs such as the heart, kidneys, brain, and retina [3,4].

The pathophysiology of hypertension is complex and involves multiple neurohormonal and vascular regulatory systems, including the Renin–Angiotensin–Aldosterone System (RAAS), sympathetic nervous system (SNS), natriuretic peptides, and endothelial-derived vasoactive substances. Among these, the RAAS plays a crucial role in blood pressure regulation. Reduced renal perfusion, decreased sodium delivery, or sympathetic stimulation triggers the release of renin from the juxtaglomerular cells of the kidney. Renin converts angiotensinogen into angiotensin I, which is subsequently converted into angiotensin II by angiotensin-converting enzyme (ACE) in the lungs. Angiotensin II is a potent vasoconstrictor and stimulates aldosterone secretion from the adrenal cortex, resulting in sodium and water retention, thereby increasing blood pressure. In addition, vasopressin release contributes to fluid retention and vascular tone regulation [5,6].

Natriuretic peptides such as atrial natriuretic peptide (ANP) and brain natriuretic peptide (BNP) act as physiological counter-regulatory mechanisms by promoting natriuresis, vasodilation, and reduction in plasma volume. Similarly, endothelial-derived substances such as nitric oxide and endothelin regulate vascular tone and blood vessel homeostasis. Dysfunction in endothelial regulation leads to increased vasoconstriction and elevated blood pressure. The sympathetic nervous system also plays a significant role in maintaining blood pressure by increasing heart rate, myocardial contractility, and peripheral vasoconstriction. Persistent sympathetic activation increases cardiac output and systemic peripheral resistance, contributing to sustained hypertension [7].

Hypertension is clinically categorized into normal blood pressure, elevated blood pressure, Stage 1 hypertension, Stage 2 hypertension, and hypertensive crisis based on systolic and diastolic blood pressure values. It is broadly classified into primary (essential) hypertension and secondary hypertension. Primary hypertension accounts for the majority of cases and has no identifiable underlying cause, whereas secondary hypertension occurs due to underlying pathological conditions such as renal disease, endocrine disorders, neurological disorders, thyroid abnormalities, or cardiovascular diseases [8]. Hypertensive urgency is characterized by severe blood pressure elevation without acute target organ damage, whereas hypertensive emergency involves severe hypertension associated with acute end-organ damage requiring immediate medical intervention [9].

Although the effects of hypertension on left ventricular structure and function have been extensively studied, the impact of systemic hypertension on right heart function has received relatively less attention. Chronic hypertension can indirectly affect right ventricular structure and performance through ventricular interdependence, pulmonary vascular alterations, and increased afterload. The right ventricle is particularly sensitive to changes in preload and afterload, and subtle functional impairment may occur before overt clinical manifestations [10,11].

Echocardiography remains a reliable, non-invasive imaging modality for evaluating right heart structure, hemodynamics, and functional parameters. Assessment of right atrial pressure can be performed by evaluating the inferior vena cava (IVC) diameter and its inspiratory collapsibility. Normally, a compliant IVC demonstrates significant inspiratory collapse; however, elevated right atrial pressure leads to IVC dilatation with reduced collapse. Tricuspid Annular Plane Systolic Excursion (TAPSE) is one of the most widely used echocardiographic parameters for assessing right ventricular systolic function [12].

TAPSE measures the longitudinal systolic movement of the lateral tricuspid annulus and correlates well with right ventricular ejection fraction. A TAPSE value of less than 17 mm is indicative of right ventricular systolic dysfunction. In addition, right ventricular diastolic function can be assessed using tricuspid inflow velocities, E/A ratio, tissue Doppler imaging, and deceleration time, which provide valuable insights into right ventricular relaxation and filling patterns [13].

Hemodynamic parameters such as right atrial pressure, pulmonary artery systolic pressure, pulmonary artery end-diastolic pressure, and mean pulmonary artery pressure can also be estimated using Doppler echocardiography, providing important information about right heart loading conditions and pulmonary circulation. These parameters help identify subclinical right ventricular dysfunction and pulmonary hypertension in hypertensive patients [14].

Despite the high prevalence of hypertension and its known cardiovascular complications, limited data are available regarding the progression of right heart dysfunction across different stages of hypertension. Early identification of right ventricular involvement may provide important prognostic information and help guide timely therapeutic interventions [15, 16]. Therefore, the present study aims to evaluate echocardiographic parameters of right heart function in patients with various stages of hypertension and to determine the association between hypertension severity and right ventricular functional impairment.

Materials and Methods

Study Design and Setting: This study was designed as a cross-sectional observational study to evaluate right heart function using echocardiographic parameters among patients with various stages of hypertension. The study was conducted in the Department of Cardiology at a tertiary care teaching hospital. All echocardiographic examinations were performed in the echocardiography laboratory under standardized conditions using conventional transthoracic echocardiographic techniques.

Study Population: The study population included adult patients diagnosed with hypertension attending the cardiology outpatient department and inpatient services during the study period. Participants were categorized based on the severity of hypertension according to standard blood pressure classification guidelines.

Sample Size: A total of 50 hypertensive patients were included in the study. The sample size was determined based on the availability of eligible participants during the study period and to ensure adequate representation across different stages of hypertension.

Sampling Technique: A convenience sampling technique was used to recruit eligible participants who fulfilled the inclusion criteria during the study period.

Inclusion Criteria: Patients aged 18 years and above with a confirmed diagnosis of hypertension were included in the study. Patients with Stage 1, Stage 2, and Stage 3 hypertension who were willing to participate and provide informed consent were enrolled.

Exclusion Criteria: Patients with known congenital heart disease, significant valvular heart disease, cardiomyopathy, chronic pulmonary disease, pulmonary hypertension due to primary lung pathology, pericardial disease, chronic kidney disease requiring dialysis, or poor echocardiographic window were excluded from the study. Pregnant women and critically unstable patients were also excluded.

Ethical Approval: The study protocol was reviewed and approved by the Institutional Ethics Committee before commencement of the study. Written informed consent was obtained from all participants prior to enrollment, and the study was conducted in accordance with ethical principles outlined in the World Medical Association Declaration of Helsinki.

Clinical Evaluation and Echocardiographic Assessment: A detailed clinical evaluation was performed for all participants, including demographic data, medical history, duration of hypertension, medication history, and associated comorbidities. Blood pressure was measured using a standardized sphygmomanometer after the patient had rested for at least 5 minutes in a seated position. Three readings were taken at regular intervals, and the average value was recorded for classification of hypertension severity. Heart rate, body mass index (BMI), and relevant cardiovascular symptoms were also documented. Transthoracic echocardiography was performed using the GE HealthCare Vivid S5 echocardiography system. Standard two-dimensional (2D), M-mode, pulse-wave Doppler (PWD), continuous-wave Doppler (CWD), and tissue Doppler imaging (TDI) were used to assess right heart structure and function. Standard echocardiographic views including Parasternal Long Axis (PLAX), Parasternal Short Axis (PSAX), Apical 2-Chamber (A2C), Apical 4-Chamber (A4C), Apical 5-Chamber (A5C), Apical 3-Chamber (A3C), right ventricular inflow view, and subcostal view were obtained. Right atrial pressure (RAP) was estimated based on inferior vena cava (IVC) diameter and inspiratory collapsibility. Pulmonary artery systolic pressure (PASP) was calculated from peak tricuspid regurgitation velocity using the modified Bernoulli equation: $PASP=4V^2+RAP$.

Pulmonary artery end-diastolic pressure (PAEDP) was calculated using pulmonary regurgitation end-diastolic velocity: $PAEDP=4V^2+RAP$. Mean pulmonary artery pressure (MPAP) was calculated using: $MPAP=PASP+2(PAEDP)/3$. Right ventricular systolic function was assessed using Tricuspid Annular Plane Systolic Excursion (TAPSE), measured by M-mode in the apical four-chamber view. Right ventricular diastolic function was assessed using tricuspid inflow E/A ratio and deceleration time (DT). All measurements were performed according to standard echocardiographic guidelines for right heart assessment [7,8].

Results

A total of 50 hypertensive patients were included in the study and classified according to the severity of hypertension. Among the study population, 11 patients (22%) were categorized as pre-hypertensive, 16 patients (32%) as Stage 1 hypertension, 14 patients (28%) as Stage 2 hypertension, and 9 patients (18%) as Stage 3 hypertension, as shown in **Table 1**.

STAGESOF HYPERTENSION	NO OF PATIENTS	PERCENTAGE %
PRE-HYPERTENSION	11	22%
STAGE 1	16	32%
STAGE 2	14	28%
STAGE 3	9	18%

TABLE 1. DISTRIBUTION OF STAGES OF VHYPERTENSION AMONG THE POPULATION

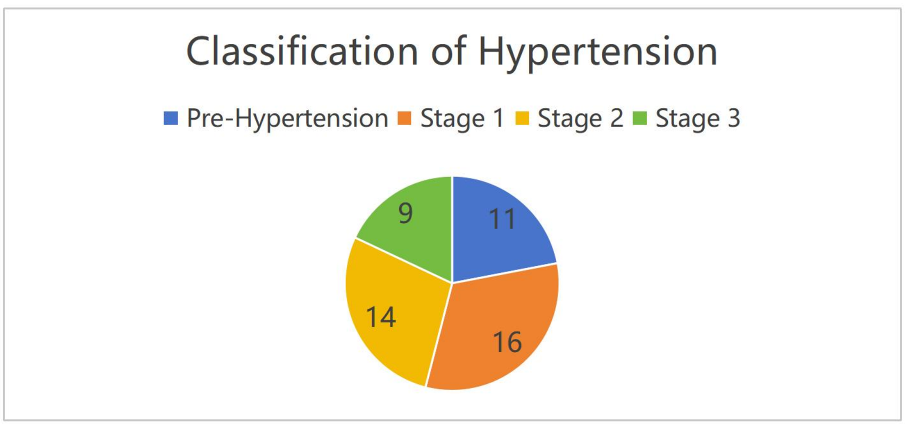

Figure 1. Represents the Classification of Hypertension Patients

Stage 1 hypertension represented the highest proportion of cases in the study population, followed by Stage 2 hypertension, pre-hypertension, and Stage 3 hypertension. The distribution of hypertensive stages among the study participants is illustrated in **Figure 1**.

CO-MORBIDITIES	NO OF PATIENTS	PERCENTAGE %
DIABETES MELLITUS	32	21%
DYSLIPIDEMIA	19	12%
ACUTE KIDNEY INJURY	11	7%
CHRONIC KIDNEY DISEASE	21	14%
COPD	23	15%
PULMONARY THROMBOEMBOLISM	20	13%
ACUTE PULMONARY EDEMA	18	12%
BRONCHIAL ASTHMA	9	6%

TABLE 2. DISRTIBUTION OF CO-MORBITIES AMONG THE POPULATION

The distribution of co-morbidities among the study population is presented in **Table 2**. Diabetes mellitus was the most common co-morbidity, observed in 32 patients (21%), followed by chronic obstructive pulmonary disease (COPD) in 23 patients (15%), chronic kidney disease in 21 patients (14%), pulmonary thromboembolism in 20 patients (13%), dyslipidemia in 19 patients (12%), acute pulmonary edema in 18 patients (12%), acute kidney injury in 11 patients (7%), and bronchial asthma in 9 patients (6%). The overall co-morbidity distribution is represented in **Figure 2**.

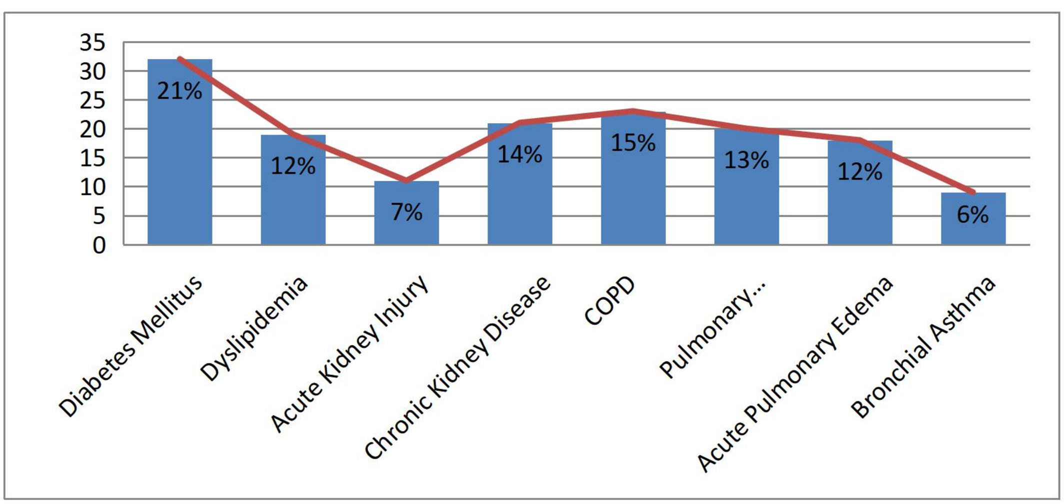

Figure 2. Represents the Co-Morbidities of the included Sample

The echocardiographic parameters assessed in this study included right heart hemodynamic parameters, right ventricular systolic function, and right ventricular diastolic function, as listed in **Table 3**. Hemodynamic parameters included right atrial pressure (RAP), pulmonary artery systolic pressure (PASP), pulmonary artery end-diastolic pressure (PAEDP), and mean pulmonary artery pressure (MPAP). Right ventricular systolic function was evaluated using Tricuspid Annular Plane Systolic Excursion (TAPSE), while right ventricular diastolic function was assessed using tricuspid E/A ratio and deceleration time (DT).

HEMODYNAMIC PARAMETERS	RAP (Right atrial pressure) cm^2
	PASP (Pulmonary artery systolic pressure) mmHg
	PAEDP (Pulmonary artery end-diastolic pressure) mmHg
	MPAP (Mean pulmonary artery pressure) mmHg
RV SYSTOLIC FUNCTION	TAPSE (Tricuspid annular plane systolic excursion) mm
RV DIASTOLIC FUNCTION	E/A Ratio
	DT (Deceleration time)ms

TABLE 3. LIST OF ECHOCARDIOGRAPHIC PARAMETERS

Right atrial pressure (RAP) demonstrated progressive changes across different stages of hypertension, with increased values observed in advanced stages, indicating elevated right-sided filling pressures. These changes are represented in **Figure 3**. Pulmonary artery systolic pressure (PASP) also showed a progressive increase with advancing stages of hypertension, suggesting increased pulmonary vascular resistance and elevated right ventricular afterload, as shown in **Figure 4**.

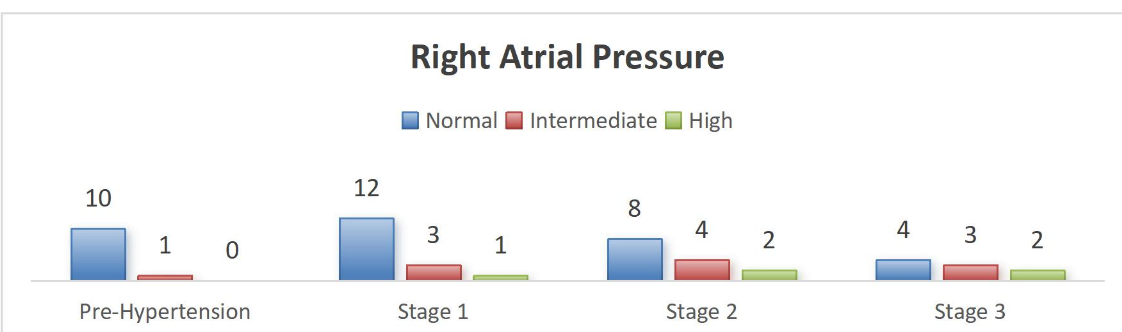

Figure 3. Represents the Right Atrial Pressure Changes (RAP)

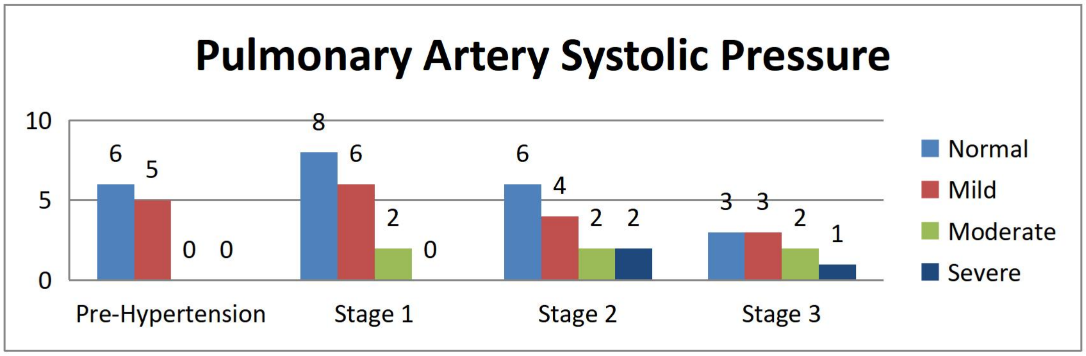

Figure 4. Represents the changes in Pulmonary Artery Systolic Pressure (PASP)

Pulmonary artery end-diastolic pressure (PAEDP) showed a similar increasing trend in severe hypertension, reflecting increased pulmonary artery pressure and right ventricular loading conditions (**Figure 5**). Mean pulmonary artery pressure (MPAP) demonstrated significant elevation across advanced hypertensive stages, indicating progressive pulmonary hemodynamic involvement (**Figure 6**).

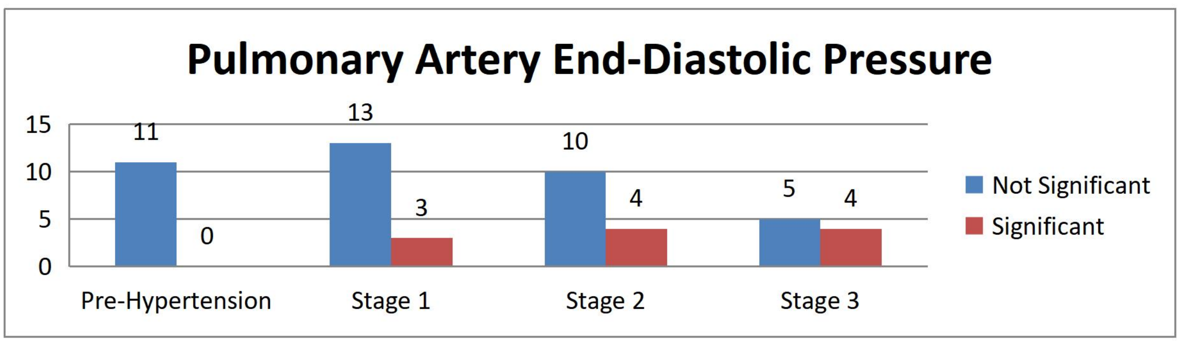

Figure 5. Represents the changes in Pulmonary Artery End-diastolic Pressure (PAEDP)

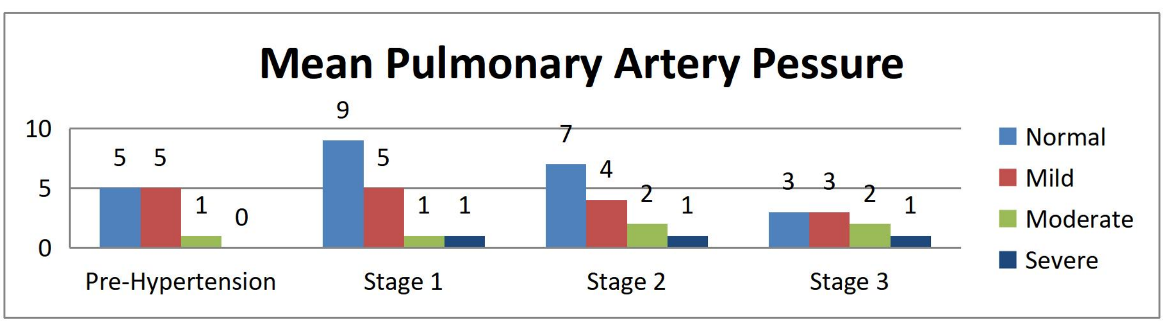

Figure 6. Represents the changes in Mean Pulmonary Artery Pressure (MPAP)

Right ventricular systolic function, assessed by TAPSE, showed a declining trend with increasing hypertension severity. Reduced TAPSE values were more prominent in Stage 2 and Stage 3 hypertension, indicating progressive right ventricular systolic dysfunction. These findings are illustrated in **Figure 7**.

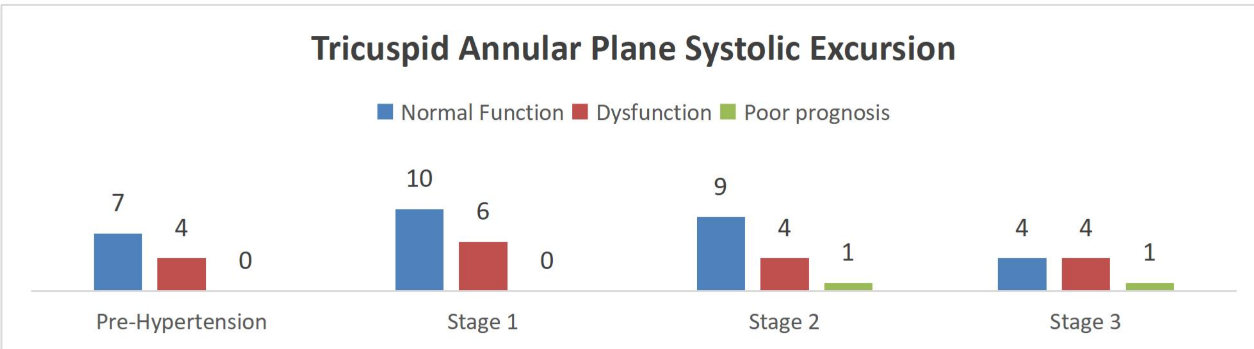

Figure 7. Represents the changes in Tricuspid Annular Plane Systolic Excursion (TAPSE)

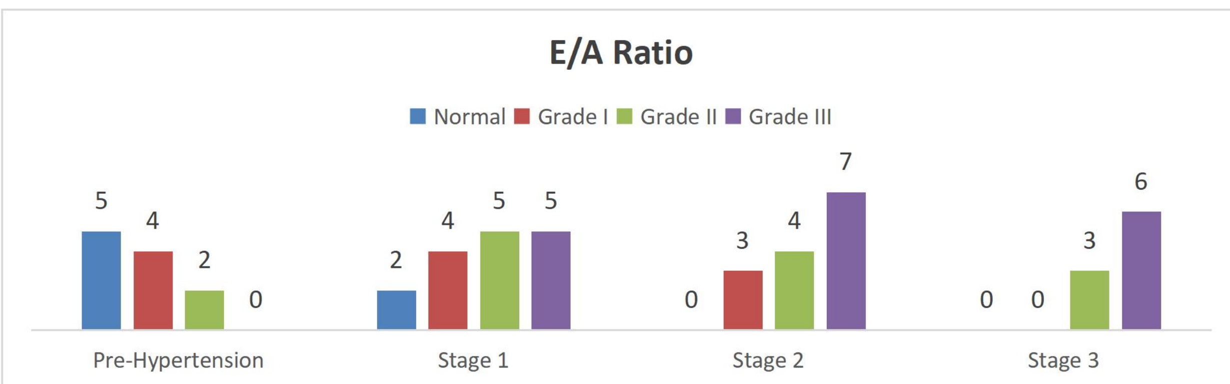

Figure 8. Represents the changes in E/A ratio

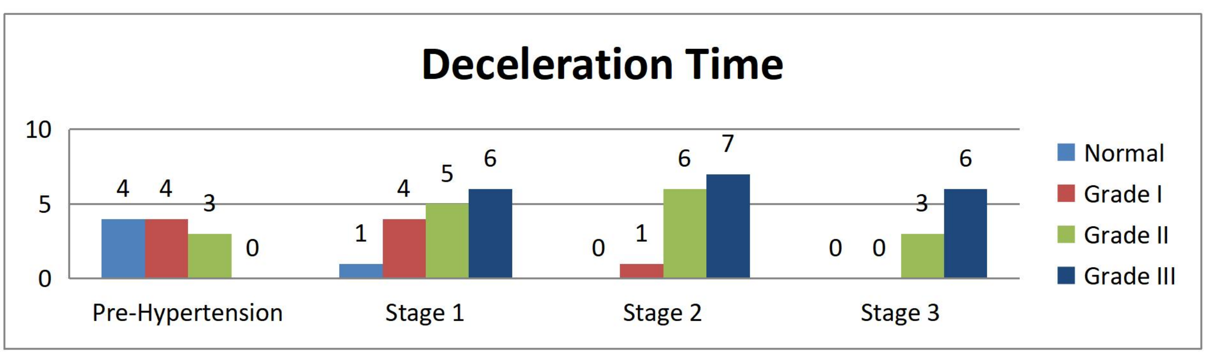

Figure 9. Represents the changes in Deceleration Time (DT)

Right ventricular diastolic function assessment showed alterations in the tricuspid E/A ratio across the different stages of hypertension, suggesting progressive impairment in right ventricular relaxation and filling patterns (**Figure 8**). Similarly, deceleration time (DT) demonstrated significant changes, indicating worsening right ventricular diastolic dysfunction with increasing hypertension severity, as represented in **Figure 9**.

Overall, the results demonstrate that progressive hypertension is associated with significant alterations in right heart hemodynamics, right ventricular systolic performance, and right ventricular diastolic function, emphasizing the importance of early echocardiographic evaluation for detecting right heart involvement in hypertensive patients.

Discussion

The present cross-sectional observational study aimed to evaluate right heart function in hypertensive patients using echocardiographic parameters and to determine its association with the severity of hypertension. A total of 50 hypertensive patients were included, comprising 29 males (58%) and 21 females (42%). The majority of the study population belonged to the 40–60 years age group (48%), followed by 20–40 years (31%) and 60–80 years (21%), indicating that hypertension was predominantly observed in middle-aged individuals. This observation is consistent with the well-established increase in hypertension prevalence with advancing age and its progressive cardiovascular impact.

Hypertension is frequently associated with multiple co-morbid conditions that may accelerate cardiovascular remodeling and adversely affect cardiac function. In the present study, diabetes mellitus was the most common co-morbidity, followed by chronic obstructive pulmonary disease, chronic kidney disease, pulmonary thromboembolism, dyslipidemia, acute pulmonary edema, acute kidney injury, and bronchial asthma. The coexistence of these conditions may contribute to alterations in systemic and pulmonary hemodynamics, thereby increasing the burden on right ventricular function. Previous studies have shown that metabolic and renal dysfunction can significantly influence ventricular remodeling and worsen cardiovascular outcomes [1,2].

Echocardiographic assessment in this study included evaluation of right-sided hemodynamic parameters such as right atrial pressure (RAP), pulmonary artery systolic pressure (PASP), pulmonary artery end-diastolic pressure (PAEDP), and mean pulmonary artery pressure (MPAP), in addition to right ventricular systolic and diastolic functional assessment. The findings demonstrated that hemodynamic parameters did not show significant alterations in the early stages of hypertension. This suggests that pressure-related changes in the right heart may not be prominent during the initial stages of systemic hypertension and may develop progressively with disease advancement. Similar findings have been reported in earlier studies, where right-sided hemodynamic burden became evident only in long-standing or severe hypertension [1,3].

Right ventricular systolic function was assessed using Tricuspid Annular Plane Systolic Excursion (TAPSE), a well-established echocardiographic marker of right ventricular longitudinal systolic function. In the present study, TAPSE values remained relatively preserved in pre-hypertension and Stage 1 hypertension, with mild reduction observed in Stage 2 and Stage 3 hypertension. This finding suggests that right ventricular systolic dysfunction may occur later in the disease process, likely following structural and hemodynamic adaptation. Previous studies have similarly demonstrated that TAPSE remains preserved until significant ventricular dysfunction develops [5–7].

In contrast, right ventricular diastolic function, assessed using tricuspid inflow Doppler parameters such as E/A ratio and deceleration time (DT), demonstrated more evident abnormalities across the progressive stages of hypertension. These findings indicate that right ventricular diastolic dysfunction may occur earlier than systolic dysfunction and may represent a subclinical manifestation of right heart involvement. Alterations in diastolic filling patterns may reflect impaired ventricular relaxation, increased myocardial stiffness, and altered ventricular compliance. Similar observations have been reported by Haddad et al. and Wu et al., who emphasized the importance of early diastolic abnormalities in identifying right ventricular dysfunction [8,9].

The progressive deterioration in right ventricular diastolic parameters observed in Stage 2 and Stage 3 hypertension suggests that advanced systemic hypertension has a greater impact on right ventricular mechanics. This may be explained by ventricular interdependence, increased pulmonary vascular resistance, elevated afterload, and chronic myocardial remodeling secondary to persistent systemic pressure overload. Tumuklu et al. demonstrated that hypertension-associated left ventricular hypertrophy can significantly influence right ventricular performance through interventricular septal interaction and altered ventricular geometry [2].

The correlation between hypertensive stages and right heart dysfunction observed in this study suggests that increasing severity of hypertension is associated with progressive right ventricular functional impairment, particularly at the diastolic level. This finding has important clinical implications, as early identification of right ventricular involvement may improve cardiovascular risk stratification and facilitate timely therapeutic intervention. Routine echocardiographic evaluation of right ventricular function may therefore provide additional prognostic value in hypertensive patients, particularly those with advanced disease [10–17].

However, the present study has certain limitations. The relatively small sample size and single-center design may limit the generalizability of the findings. In addition, the cross-sectional nature of the study does not allow assessment of longitudinal progression of right ventricular dysfunction. Further large-scale prospective studies are required to validate these findings and establish the prognostic significance of right heart dysfunction in hypertensive patients.

Conclusion

Hypertension remains a major global cardiovascular risk factor and is traditionally associated with structural and functional alterations of the left heart. However, the findings of the present study demonstrate that systemic hypertension also affects right heart function, particularly in advanced stages of the disease.

Echocardiographic evaluation revealed that right ventricular diastolic dysfunction was more sensitive in detecting early right heart involvement compared to hemodynamic parameters and right ventricular systolic function. Among the assessed parameters, tricuspid inflow Doppler indices, particularly E/A ratio and deceleration time, showed greater accuracy in identifying right ventricular dysfunction and demonstrated stronger association with Stage 2 and Stage 3 hypertension. These findings suggest that right ventricular diastolic dysfunction may serve as an early marker of subclinical right heart involvement in hypertensive patients. Therefore, comprehensive echocardiographic assessment of right ventricular function should be considered in the routine evaluation of hypertensive patients, especially those with moderate to severe hypertension, to facilitate early diagnosis, improve risk stratification, and optimize clinical management strategies. Future prospective studies with larger sample sizes are warranted to further establish the clinical significance of right heart dysfunction in hypertension.

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