

Left Ventricular Diastolic Dysfunction and Its Associated Factors among Middle-Aged Hypertensive Patients: A Hospital-Based Comparative Cross-Sectional Study

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ABSTRACT

Background: Hypertension often progresses silently to left ventricular diastolic dysfunction before overt symptoms appear, and its early detection in middle-aged individuals is crucial to prevent heart failure with preserved ejection fraction. The purpose was to assess the prevalence of diastolic dysfunction and associated risk factors among middle-aged hypertensive patients and to compare the findings with age-matched normotensive controls.

Methodology: This hospital-based comparative cross-sectional study enrolled 774 participants (387 hypertensive cases, 387 normotensive controls) aged 40-60 years. All underwent two-dimensional echocardiography with tissue Doppler imaging, and diastolic dysfunction was graded by the 2016 ASE/EACVI guidelines. Data were analysed in SPSS v25.0 using the chi-square test ($p < 0.05$ significant).

Results: Diastolic dysfunction was more prevalent among cases (Grade 1, 33.07%; Grade 2, 14.47%) than controls (18.09% and 7.49%). Within the hypertensive group, substance use ($p = 0.003$), drug compliance ($p < 0.001$) and antihypertensive drug class ($p = 0.005$) differed significantly by dysfunction status, whereas age, sex and socioeconomic status did not; smoking alone was not significant ($p = 0.57$). Dysfunction was paradoxically more frequent among drug-compliant patients (55.27% vs 28.57%) and Telmisartan users, consistent with confounding by indication.

Conclusions: Diastolic dysfunction is common and frequently asymptomatic in middle-aged hypertensive adults, with Grade 1 predominating. Routine echocardiographic screening, stringent blood-pressure control and risk-factor modification are warranted to detect subclinical disease before symptomatic heart failure.

Keywords: Echocardiography, Tissue Doppler Imaging, Heart Failure with Preserved Ejection Fraction, Ventricular Remodeling, Medication Adherence, Blood Pressure

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INTRODUCTION

Non-communicable diseases account for approximately 68% of global deaths, and in India they contribute to nearly 60% of all fatalities, with cardiovascular disease, cancer, chronic respiratory disease and diabetes collectively responsible for the majority of this burden.[1] The prevalence of these conditions is rising particularly in low- and middle-income countries such as India, driven by modifiable behavioural and biological factors including tobacco and alcohol use, physical inactivity, unhealthy diet, obesity and elevated blood pressure, glucose and cholesterol. [2] Cardiovascular disease remains the leading global cause of death, responsible for an estimated 17.9 million deaths in 2016, [3] and hypertension is a critical contributor, implicated in a substantial proportion of stroke and coronary-artery-disease deaths.[4] Hypertensive patients therefore constitute the population in which the earliest reversible cardiac consequences of a modifiable risk factor can most usefully be sought.

Chronic pressure overload drives cardiac remodelling through increased afterload and myocardial fibrosis, producing both systolic and diastolic dysfunction.[5] Left ventricular diastolic dysfunction, characterised by impaired myocardial relaxation and reduced compliance, is the earliest of these changes to appear and is a recognised precursor to heart failure with preserved ejection fraction, which accounts for a large share of heart-failure cases.[6] It is an independent predictor of adverse cardiovascular outcomes, yet it is silent: asymptomatic diastolic dysfunction may be present in up to a third of hypertensive patients even in the absence of left ventricular hypertrophy, so that the condition is routinely missed unless it is deliberately looked for.[6] Diastolic dysfunction is thus the outcome of interest in the present study because it identifies hypertensive heart disease at a stage when the disease process is still amenable to modification.

The middle years of life are the point at which this window is widest: target-organ damage has often begun by this stage, but symptomatic heart failure has not yet supervened, and blood-pressure control together with risk-factor modification can still alter the natural history of the disease. Identifying which patients within this age band carry subclinical disease, and which demographic, behavioural, clinical and treatment-related characteristics accompany it, would allow limited echocardiographic capacity to be directed towards those most likely to benefit. The factors associated with diastolic dysfunction are therefore examined here alongside its prevalence, since prevalence alone does not indicate whom to screen.

Echocardiography, and in particular tissue Doppler imaging, is a reliable, non-invasive and widely available means of detecting early hypertension-related diastolic changes and of guiding therapy; the standardised criteria issued jointly by the American Society of Echocardiography and the European Association of Cardiovascular Imaging in 2016 have improved the reproducibility and

diagnostic accuracy of this assessment and allow findings from different centres to be compared on a common basis.[7]

Despite its silent progression, its prognostic weight and the availability of a standardised diagnostic method, regional data on the prevalence and echocardiographic pattern of diastolic dysfunction among middle-aged hypertensive individuals in northern India remain limited. Most available reports describe hypertensive cohorts without a concurrently recruited normotensive comparison group, so that the contribution of hypertension cannot be separated from that of age alone; and few examine treatment-related characteristics such as adherence and drug class alongside conventional risk factors. The present study was therefore undertaken in a tertiary-care hospital setting, where hypertensive attendees and age-matched normotensive attendees could be assessed on a single standardised ultrasound system by the same operators, to quantify how much of the diastolic burden in this age group is attributable to hypertension and to characterise the factors that accompany it.

The primary objective of this study was to determine, among 387 hypertensive patients aged 40-60 years attending the General Medicine and Cardiology outpatient departments of a tertiary-care teaching hospital in northern India between April 2024 and May 2025, the proportion with left ventricular diastolic dysfunction and the distribution of its echocardiographic grade, defined according to the 2016 criteria of the American Society of Echocardiography and the European Association of Cardiovascular Imaging, and to compare these proportions with those obtained in 387 age-matched normotensive individuals recruited from the same departments over the same period. The secondary objective was to determine, within the hypertensive group, whether the proportion with diastolic dysfunction differed according to age, sex, socioeconomic status, substance use, coexisting illness, duration of hypertension, adherence to anti-hypertensive therapy, class of antihypertensive agent prescribed and electrocardiographic abnormality, each of these comparisons being tested at the 5% level of statistical significance.

MATERIALS AND METHODS

Study design and setting: This was a hospital-based comparative cross-sectional study with a concurrently recruited normotensive comparison group, conducted in the Department of General Medicine of a tertiary-care teaching hospital in northern India. Participants were recruited from the General Medicine and Cardiology outpatient departments over a period of thirteen months, from April 2024 to May 2025. Each participant was evaluated on a single occasion and there was no follow-up. The exposure of interest was the presence of hypertension; the primary outcome was the presence and echocardiographic grade of left ventricular diastolic dysfunction, assessed by two-dimensional echocardiography with tis-

sue Doppler imaging. Age, sex, socioeconomic status, substance use, coexisting illness, duration of hypertension, adherence to antihypertensive therapy and the class of antihypertensive agent prescribed were recorded as covariates. The study is reported in accordance with the STROBE statement for observational studies.

Study population and eligibility criteria: A total of 387 middle-aged hypertensive patients and 387 normotensive individuals, all aged 40-60 years, were enrolled. Cases were adults with established or newly detected hypertension, defined as a systolic blood pressure of 140 mmHg or higher and/or a diastolic blood pressure of 90 mmHg or higher recorded on two separate occasions, or current use of antihypertensive medication, in accordance with JNC-7 criteria. Controls were adults attending the same outpatient departments during the same period whose blood pressure was below 140/90 mmHg on two occasions and who were receiving no antihypertensive therapy. Controls were matched to cases on age in the same 40-50 and 51-60 year strata, in a one-to-one ratio.

Participants were enrolled by consecutive sampling from among eligible attendees at the two outpatient departments. Individuals were excluded if they had atrial fibrillation, regional wall-motion abnormalities, mitral or aortic stenosis or regurgitation, congenital heart disease, cardiomyopathy, pericardial disease or cor pulmonale, since these conditions independently alter transmitral and annular Doppler indices and would invalidate the grading of diastolic function. Participants with incomplete clinical or laboratory data, and those who declined to participate, were also excluded; because participants with incomplete records were not enrolled, the analysed dataset contained no missing values.

Sample size: The sample size was calculated using the standard formula for the estimation of a single proportion, $n = Z^2P(1-P)/e^2$, taking $Z = 1.96$ for 95% confidence, an expected prevalence of diastolic dysfunction $P = 0.40$, based on published literature reporting a diastolic dysfunction prevalence of approximately 40% or higher in hypertensive populations[8] and an absolute precision $e = 0.05$. This yielded a minimum requirement of 369 participants. To allow for non-response and incomplete records the final sample was rounded up to 387 cases, with an equal number of age-matched controls, giving a total of 774 participants.

Study variables and clinical assessment: A detailed history covering age, sex, socioeconomic status, family history of cardiovascular disease, smoking, tobacco chewing, alcohol use, duration of hypertension, adherence to antihypertensive therapy and the antihypertensive agents currently prescribed was obtained from every participant using a pre-tested, structured questionnaire administered by the investigator, followed by a complete general and systemic examination. Socioeconomic status was classified using the modified Kuppuswamy scale. Adherence was recorded as compliant or non-compliant on the basis of the patient's report of regular daily intake of

the prescribed agent; participants receiving no antihypertensive treatment were classified as non-compliant.

Blood pressure was measured with a calibrated automated oscillometric device using an appropriately sized cuff on the right arm, after the participant had rested seated for at least five minutes and had abstained from tea, coffee and tobacco. Where the initial reading was 140/90 mmHg or higher, a second measurement was taken after three minutes and the average of the two readings was recorded. Baseline investigations included a complete blood count, renal and hepatic function tests, serum electrolytes, fasting lipid profile, chest radiography and a standard 12-lead electrocardiogram, which was examined for left ventricular hypertrophy, left-axis deviation and strain pattern. Fundus examination was performed to stage hypertensive retinopathy.

Echocardiographic assessment: All participants underwent transthoracic M-mode, two-dimensional and colour Doppler echocardiography with tissue Doppler imaging on a single ultrasound system (Hitachi Aloka ProSound Alpha 6; Hitachi Aloka Medical Ltd, Tokyo, Japan) fitted with a 2.5-3.5 MHz phased-array transducer, with the participant in the left lateral decubitus position and with simultaneous electrocardiographic gating. All studies were performed by the same operator, a general physician working together with a cardiologist, using a uniform acquisition protocol; the reported value for each parameter was the average of three consecutive cardiac cycles. Recordings were cross-verified by senior faculty; a formal blinded inter-observer reliability analysis was not undertaken.

The parameters measured were the transmitral peak early (E) and late (A) diastolic velocities and the E/A ratio, septal and lateral mitral annular e' velocities and the average E/e' ratio, mitral deceleration time, isovolumic relaxation time, pulmonary venous systolic-to-diastolic ratio, left atrial volume index measured by the biplane method of discs, tricuspid regurgitant jet velocity, and left ventricular ejection fraction by the modified Simpson method. Diastolic dysfunction was diagnosed and graded in participants with preserved ejection fraction ($\geq 50\%$) according to the 2016 recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Dysfunction was considered present when the majority of the key variables (septal $e' < 7$ cm/s or lateral $e' < 10$ cm/s, average $E/e' > 14$, left atrial volume index > 34 mL/m² and tricuspid regurgitation velocity > 2.8 m/s) were abnormal, and was graded as Grade 1 (impaired relaxation), Grade 2 (pseudonormal filling) or Grade 3 (restrictive filling) using the transmitral E/A ratio, average E/e' ratio, left atrial volume index and tricuspid regurgitation velocity.

Ethical considerations: The study protocol was approved by the Institutional Ethics Committee of Maharani Laxmi Bai Medical College, Jhansi, Uttar Pradesh, India (approval number 654/IEC/I/2024-2025, dated 30/04/2025), and the study was conducted in accordance with the ethical principles of the Declaration of Hel-

sinki. Written informed consent was obtained from every participant prior to enrolment, after the purpose, procedures and voluntary nature of the study had been explained in the local language. No personally identifying information was recorded on the study proforma; data were coded and stored confidentially and were accessible only to the investigators. Uniform, calibrated instruments and standardised protocols were used throughout, and clinical and echocardiographic observations were cross-verified by independent senior faculty in order to minimise observer bias.

Statistical analysis: Data were entered into Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) and analysed using SPSS Statistics version 25.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were summarised as mean $\pm$ standard deviation and categorical variables as frequencies and percentages. The distribution of continuous variables was inspected before analysis. Continuous variables that had been recorded as categories for the purposes of this analysis, namely age (40-50 and 51-60 years) and duration of hypertension (newly diagnosed, less than three years, and long-standing, more than three years), were categorised a priori and not on the basis of the observed data.

The primary analysis compared the prevalence and grade of diastolic dysfunction between hypertensive cases and normotensive controls. A secondary analysis, restricted to the hypertensive group, compared the distribution of demographic, behavioural, clinical and treatment-related characteristics between patients with and without diastolic dysfunction. The chi-square test was used for all comparisons of categorical variables, and all tests were two-tailed with the level of statistical significance set at $p < 0.05$. Substance-use and antihypertensive drug categories were not mutually exclusive and were therefore analysed as composite variables, with the individual categories examined separately where relevant. To limit the risk of type I error from multiple testing, a Bonferroni-corrected significance threshold of $p < 0.005$ (0.05 divided by the ten comparisons in Table 5) was additionally applied; on this stricter criterion the associations with drug compliance ($p < 0.001$) and with the composite substance-use distribution ($p = 0.003$) remained significant, whereas antihypertensive drug class ($p = 0.005$) lay at the threshold. In addition, a multivariable binary logistic-regression model was fitted with diastolic-dysfunction status as the dependent variable, adjusting for age, sex, socioeconomic status, smoking, tobacco use, alcohol use, diabetes, duration of hypertension and antihypertensive treatment group; adjusted odds ratios (aOR) with 95% confidence intervals are reported (Table 6).

RESULTS

A total of 774 participants were studied. The majority (481; 62.14%) were aged 40-50 years and the remainder (293; 37.86%) were aged 51-60 years. The sexes were

almost equally represented, with 388 males (50.13%) and 386 females (49.87%). Nearly half the participants belonged to the lower socioeconomic class (376; 48.58%), followed by the middle (316; 40.83%) and upper (82; 10.59%) classes (Table 1).

Substance use was more frequent among hypertensive cases than controls. Smoking was reported by 44.96% of cases versus 24.81% of controls, and tobacco use by 25.84% versus 16.54%, respectively; the majority of controls (65.37%) reported no history of addiction (Table 2).

Good adherence to antihypertensive therapy was recorded in 71.06% of cases, in contrast to only 16.28% of controls, the majority of whom were not on medication (Table 3). Within the hypertensive group, most patients had long-standing disease (>3 years; 67.18%), while 32.82% were newly diagnosed.

Table 1: Baseline demographic characteristics of the study population (N = 774)

Characteristic	Patients (%)
Age	
40-50 years	481 (62.14)
51-60 years	293 (37.86)
Gender	
Male	388 (50.13)
Female	386 (49.87)
Socioeconomic class	
Lower	376 (48.58)
Middle	316 (40.83)
Upper	82 (10.59)

Table 2: Comparison of substance-use history between cases and controls

Addiction	Cases (%) (n=387)	Controls (%) (n=387)
Smoker	174 (44.96)	96 (24.81)
Tobacco	100 (25.84)	64 (16.54)
Alcohol	24 (6.2)	8 (2.07)
No history	171 (44.19)	253 (65.37)

Table 3: Antihypertensive drug compliance in cases and controls

Drug history	Cases (%) (n=387)	Controls (%) (n=387)
Drug compliant	275 (71.06)	63 (16.28)
Drug non-compliant	112 (28.94)	324 (83.72)

Table 4: Duration of hypertension and antihypertensive drug distribution among cases (n = 387)

Parameter	Patients (%)
Newly diagnosed hypertension (<3 years)	127 (32.82)
Old, treated hypertension (>3 years)	260 (67.18)
Telmisartan	204 (52.71)
Amlodipine	107 (27.65)
Metoprolol	34 (8.79)
Clonidine	19 (4.91)
Ramipril	8 (2.07)

Telmisartan was the most commonly prescribed agent (52.71%), followed by Amlodipine (27.65%), Metoprolol (8.79%), and Clonidine (4.91%) (Table 4).

Echocardiographic evaluation demonstrated a higher prevalence and greater severity of diastolic dysfunction among hypertensive cases than controls. Grade 1 dysfunction was observed in 33.07% of cases (128/387) compared with 18.09% of controls (70/387), and Grade 2 dysfunction in 14.47% (56/387) compared with 7.49% (29/387), respectively; diastolic dysfunction of any grade was thus present in 184 (47.55%) cases and 99 (25.58%) controls (Figure 1).

On analysis of the factors associated with diastolic dysfunction among the hypertensive group (Table 5), no significant relationship was found with age ($p=1.00$), sex ($p=1.00$) or socioeconomic status ($p=0.70$). The overall pattern of substance use differed between patients with and without diastolic dysfunction ($p=0.003$); on examination of the individual categories, however, this difference was driven entirely by tobacco chewing, which was significantly less frequent among those with dysfunction (15.76% versus 34.98%; $p<0.001$), whereas the proportion of smokers was comparable in the two groups and not significantly different (46.74% versus 43.35%; $p=0.57$). Drug compliance was significantly associated with diastolic dysfunction ($p<0.001$), although in an unexpected direction: dysfunction was present in 55.27% (152/275) of compliant patients compared with 28.57% (32/112) of non-compliant patients (equivalently, 82.61% of patients with dysfunction were drug-compliant versus 60.59% of those without). The distribution of antihypertensive agents likewise differed significantly ($p=0.005$), with Telmisartan use recorded in 63.59% of patients with dysfunction compared with 42.86% of those without ($p<0.001$). Diabetes and other comorbidities, duration of

hypertension and electrocardiographic abnormalities such as left ventricular hypertrophy, left-axis deviation and strain pattern were not significantly associated with diastolic dysfunction (Table 5).

In the multivariable logistic-regression model (Table 6), tobacco use remained independently and inversely associated with diastolic dysfunction (aOR 0.41, 95% CI 0.23-0.71; $p=0.002$). Relative to untreated (non-compliant) patients, those receiving antihypertensive treatment had substantially higher adjusted odds of dysfunction - Telmisartan-based regimens aOR 3.99 (95% CI 2.29-6.96; $p<0.001$) and other active regimens aOR 2.04 (95% CI 1.07-3.91; $p=0.030$) - indicating that the apparent associations with drug compliance and drug class reflect treatment being a marker of established hypertension (confounding by indication) rather than a harmful drug effect. Age, sex, socioeconomic status, smoking and alcohol use were not independently associated with dysfunction.

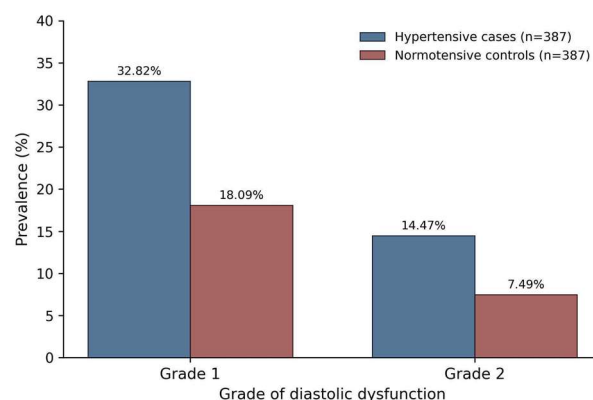


Figure 1: Prevalence of Grade 1 and Grade 2 diastolic dysfunction in hypertensive cases versus normotensive controls

Table 5: Association of clinical and risk factors with diastolic dysfunction among hypertensive patients (n = 387)

Parameter	DD present (n=184)	DD absent (n=203)	p-value
Age 40-50 / 51-60 years	113 / 71	125 / 78	1.00
Male / Female	92 / 92	102 / 101	1.00
Socioeconomic (L / M / U)	90 / 77 / 17	98 / 81 / 24	0.70
Smoker	86	88	0.57
Tobacco	29	71	<0.001
Alcohol	9	15	
No addiction	94	77	
Diabetes mellitus	35	55	0.29
Chronic liver disease	20	21	
COPD / COAD	8 / 12	20 / 11	
Hypothyroidism	6	5	
Drug compliant	152	123	<0.001
Drug non-compliant	32	80	
Newly diagnosed / Old HTN	65 / 119	62 / 141	0.37
Telmisartan	117	87	0.005
Amlodipine	61	46	
Ramipril / Clonidine / Metoprolol	8 / 12 / 28	0 / 7 / 6	

DD = diastolic dysfunction; HTN = hypertension; LVH = left ventricular hypertrophy; LAD = left-axis deviation; L/M/U = lower/middle/upper. Substance-use and antihypertensive categories are not mutually exclusive; hence, totals may exceed group denominators. $p<0.05$ was considered significant. For substance use, the reported p value is the composite Addiction chi-square ($p=0.003$); individual categories: smoker ($p=0.57$) and tobacco ($p<0.001$).

Table 6: Multivariable logistic-regression model of factors independently associated with diastolic dysfunction among hypertensive patients (n = 387)

Variable	Adjusted OR	95% CI	p-value
Age (per year)	1.02	0.99-1.05	0.27
Male sex	0.96	0.59-1.56	0.87
Socioeconomic status: middle	1.04	0.66-1.63	0.88
Socioeconomic status: upper	0.78	0.37-1.63	0.51
Smoking	1.14	0.69-1.89	0.60
Tobacco use	0.41	0.23-0.71	0.002
Alcohol use	0.75	0.29-1.92	0.55
Diabetes	0.59	0.35-0.99	0.045
Hypertension >3 years	0.60	0.36-0.99	0.044
Telmisartan-based regimen	3.99	2.29-6.96	<0.001
Other active regimen	2.04	1.07-3.91	0.030

aOR = adjusted odds ratio. Reference categories: female sex, lower socioeconomic status, absence of the respective substance use or comorbidity, hypertension ≤ 3 years, and untreated (non-compliant) for the treatment-group variable. Model fitted on 387 hypertensive cases (184 with and 203 without diastolic dysfunction). $p < 0.05$ considered significant.

DISCUSSION

This study shows that left ventricular diastolic dysfunction is common among middle-aged hypertensive adults, and that hypertension rather than age alone accounts for much of that burden: dysfunction was present in almost half of the hypertensive group and in a quarter of the age-matched normotensive individuals recruited from the same departments over the same period. The answer to the second question is that, within the hypertensive group, the presence of dysfunction was not explained by age, sex, socioeconomic status or smoking, but was associated with adherence to antihypertensive therapy and with the class of agent prescribed. Both of these treatment-related associations, on examination, reflect who receives and takes treatment rather than any effect of treatment on the myocardium.

The magnitude of the difference between the two groups supports this answer. Almost twice as many hypertensive participants as normotensive participants had dysfunction of any grade, and the excess was present at both grades measured, so it does not depend on where the threshold for abnormality is placed. Grade 1 dysfunction predominated in both groups, which places most of the disease detected here at the stage of impaired relaxation rather than of established filling-pressure elevation. This gradient is consistent with the reported positive correlation between the severity of hypertension and the grade of diastolic dysfunction.[9] That the majority of these participants were asymptomatic is the practical point: disease at this stage declares itself on echocardiography and in almost no other way.

Within the hypertensive group, no association was found between diastolic dysfunction and age, sex or socioeconomic status. The absence of a difference between the sexes accords with earlier reports in which the preva-

lence of diastolic dysfunction did not differ significantly between men and women,[10] although population-based work has emphasised the influence of demographic and socioeconomic factors on ventricular geometry and diastolic function. [11] A likely explanation for the null result here is the narrow age band studied: with all participants aged between 40 and 60 years and controls matched within the same strata, the range of age was deliberately compressed, and the study was not designed to detect an age gradient within it. The predominance of participants in the 40-50-year subgroup nevertheless underlines the value of screening even in relatively younger hypertensive adults.

The overall pattern of substance use differed significantly between hypertensive patients with and without diastolic dysfunction, but this result requires careful interpretation and does not implicate smoking. When the categories were examined separately, the proportion of smokers was almost identical in the two groups and the difference was not significant; the significant result for the composite variable was driven by tobacco chewing, which was less frequent among patients with dysfunction. Because the addiction categories were not mutually exclusive, a significant chi-square value for the group as a whole cannot be attributed to any one of its constituent exposures. The present data therefore do not support smoking as a risk factor for diastolic dysfunction in this cohort, notwithstanding reports of such an association elsewhere.[12]

The association with drug compliance was the most unexpected finding of this study, since dysfunction was more frequent among compliant than among non-compliant patients. Three explanations were considered. A direct harmful effect of adherence is not biologically tenable and is contradicted by the established protective role of sustained blood-pressure control.[13] Reverse causation, in which the diagnosis itself improved adherence, is unlikely because the echocardiogram was performed after enrolment and its result was not known to the patients beforehand. The remaining and most plausible explanation is confounding by indication: patients with longer-standing or more severe hypertension, a greater symptom burden and established target-organ damage are precisely those most likely to be engaged with treatment and therefore adherent. This interpretation is supported by the structure of the present cohort, in which every non-compliant patient was in fact receiving no antihypertensive treatment at all, so that the comparison is effectively between treated and untreated hypertension rather than between good and poor adherence. Consistent with it, longer duration of hypertension was associated with a numerically higher burden of myocardial involvement, although the difference did not reach statistical significance, a trend also noted in longitudinal work relating midlife blood pressure to future diastolic dysfunction.[14]

The same reasoning applies to the distribution of antihypertensive agents. Telmisartan was the most frequently prescribed drug in this cohort and was recorded more

often among patients with dysfunction than among those without, but this association is almost certainly non-causal. Angiotensin-receptor blockers have recognised favourable effects on myocardial fibrosis and ventricular remodelling, and it would be biologically implausible for Telmisartan to precipitate diastolic dysfunction;[15] the finding is better read as a reflection of prescribing practice, in that patients with more advanced hypertensive heart disease are preferentially commenced on renin-angiotensin system blockade. A further consideration is that fixed-dose combinations were counted under the angiotensin-receptor blocker category, so that the drug-wise frequencies indicate the regimen received rather than exposure to a single agent. In an observational design of this kind the direction of such treatment-related associations cannot be resolved, and no inference about drug efficacy or harm should be drawn from these data.

Electrocardiographic abnormalities did not identify the patients with diastolic dysfunction. Left ventricular hypertrophy, left-axis deviation and strain pattern were no more frequent among those with dysfunction than among those without, which is consistent with reports that reliance on electrocardiography alone underestimates the true prevalence of diastolic dysfunction.[12] Taken together with the difference between the hypertensive and normotensive groups, this has a direct bearing on practice: in a middle-aged hypertensive population of the kind seen in Indian tertiary-care outpatient departments, neither symptoms, nor conventional risk-factor profiling, nor the electrocardiogram reliably identifies who carries subclinical hypertensive heart disease, and echocardiography is required to do so. These findings agree with previous community- and hospital-based studies emphasising the prognostic importance of early detection and aggressive risk-factor management.[16,17]

STRENGTH AND LIMITATIONS

The principal strength of this study is its adequately powered sample of 774 participants, including an age-matched normotensive comparison group recruited concurrently from the same departments, allowing the contribution of hypertension to be distinguished from age. Diastolic function was assessed using tissue Doppler imaging on a standardised ultrasound system according to the 2016 ASE/EACVI criteria, with echocardiographic findings independently cross-verified by senior faculty. Uniform calibrated instruments and a standardised questionnaire further supported internal validity.

The single-centre, tertiary-care and hospital-based setting may limit generalisability, and the reported prevalence may exceed community estimates; however, concurrent recruitment of controls from the same departments and period strengthened between-group comparisons. The cross-sectional design precludes causal inference. Associations with drug compliance and Telmisartan use may be affected by confounding by indication, as they were not adjusted for hypertension severity, duration, or left ventricular mass. Multivariable

logistic regression and Bonferroni correction were applied, although residual confounding remains possible. Finally, categorical BP control, non-mutually exclusive addiction categories, and single-category classification of fixed-dose combinations limited interpretation of corresponding analyses.

The principal strength of this study is its comparatively large, adequately powered sample of 774 participants,

CONCLUSION

Left ventricular diastolic dysfunction is common in middle-aged hypertensive adults and is attributable to hypertension rather than to age, being substantially more frequent than in age-matched normotensive individuals. It is predominantly of early grade and largely asymptomatic, and it is not identified by demographic profiling or by the electrocardiogram. The associations observed with treatment adherence and with drug class reflect who receives and takes antihypertensive treatment, not an effect of that treatment on the myocardium.

RECOMMENDATIONS

Clinicians may wish to consider more systematic echocardiographic assessment of diastolic function in hypertensive adults in this age group, even when they are asymptomatic, alongside stringent blood-pressure control and modification of conventional cardiovascular risk factors, pending confirmation in adjusted, multicentre studies. Prospective, multicentre studies incorporating multivariable adjustment for hypertension severity, duration of disease and left ventricular mass are required to establish which factors are independently associated with diastolic dysfunction in this population.

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Individual Author's Contribution: **BV** conceived and designed the study, collected the data, performed data analysis and interpretation, drafted the manuscript, and approved the final version. **RJ** contributed to the study conception and design, participated in data analysis and interpretation, critically revised the manuscript, and approved the final version. **DB** contributed to the study conception and design, assisted with data analysis and interpretation, critically reviewed the manuscript, and approved the final version. **RR** contributed to the study conception and design, participated in data analysis and interpretation, critically revised the manuscript, and ap-

proved the final version. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

Availability of data: The data that support the findings of this study are available from the corresponding author on reasonable request.

Declaration of Non-use of generative AI Tools: The authors declare that no generative artificial intelligence (AI) tools were used in the conception or design of the study, the collection, analysis or interpretation of data, or the writing or revision of any part of this manuscript. All content was prepared, reviewed and approved solely by the authors, who take full responsibility for the integrity and accuracy of the work.

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