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Original Article

Blood Pressure Variability in Young Adults and Its Association with Lifestyle Factors: A Cross-Sectional Study

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ABSTRACT

Background: Blood pressure variability (BPV) — the fluctuation of blood pressure over short- and long-term periods — has emerged as an independent predictor of cardiovascular risk, target-organ damage, and future hypertension, even in individuals with normal mean blood pressure. While BPV has been extensively studied in the elderly and in hypertensive populations, data on its determinants among apparently healthy young adults, particularly in relation to modifiable lifestyle behaviours, remain limited in the Indian context.
Objectives: To measure short-term (within-visit and day-to-day) blood pressure variability in young adults aged 18–30 years and to evaluate its association with lifestyle factors including physical activity, dietary salt intake, sleep duration, smoking, alcohol use, screen time, and perceived stress.
Materials and Methods: A cross-sectional observational study was conducted among 300 apparently healthy young adults recruited from a community setting. Blood pressure was recorded in triplicate on three separate occasions using a validated automated oscillometric device, and variability indices (standard deviation [SD], coefficient of variation [CV], and average real variability [ARV]) were derived. Lifestyle data were collected using structured, pre-validated questionnaires (WHO STEPS instrument for physical activity, Pittsburgh Sleep Quality Index for sleep, and a perceived stress scale). Associations were tested using Pearson/Spearman correlation, independent t-tests, ANOVA, and multivariable linear regression, with $p < 0.05$ considered statistically significant.
Results: The mean systolic BP-SD was 8.4 ± 2.9 mmHg and diastolic BP-SD was 6.7 ± 2.3 mmHg. Higher systolic BPV was significantly associated with low physical activity ($p < 0.001$), high dietary salt intake ($p = 0.002$), short sleep duration < 6 hours ($p < 0.001$), current smoking ($p = 0.004$), higher screen time ($p = 0.01$), and higher perceived stress scores ($p < 0.001$). On multivariable regression, sleep duration ($\beta = -0.31$), physical activity level ($\beta = -0.27$), and perceived stress ($\beta = 0.24$) emerged as independent predictors of systolic BPV after adjusting for age, sex, and body mass index (adjusted $R^2 = 0.38$).
Conclusion: Blood pressure variability is measurable and clinically relevant even in young, apparently healthy adults and is significantly influenced by modifiable lifestyle factors, particularly sleep quality, physical inactivity, and psychological stress. Early lifestyle modification may help reduce long-term cardiovascular risk associated with elevated BPV.

Keywords*: Blood pressure variability; young adults; lifestyle factors; physical activity; sleep duration; cardiovascular risk; India.*

INTRODUCTION

Blood pressure (BP) is not a static physiological parameter; it fluctuates continuously in response to autonomic, hormonal, behavioural, and environmental influences. Blood pressure variability (BPV) refers to the degree of fluctuation of BP over a given period and is broadly classified into very short-term (beat-to-beat), short-term (within 24 hours), mid-term (day-to-day), and long-term (visit-to-visit or seasonal) variability [1]. Over the past two decades, a substantial body of evidence

has shown that increased BPV is associated with target-organ damage, subclinical atherosclerosis, and cardiovascular events independent of mean BP values [2]. This has shifted clinical and research attention from BP as a single measured value toward BP as a dynamic, time-varying trait.

Traditionally, hypertension research has focused on middle-aged and elderly populations, where BPV has been consistently linked to stroke, cognitive decline, and renal impairment [3]. However, a growing body of literature indicates that the origins of abnormal BP regulation and heightened variability may lie much earlier in life. Vascular stiffening, endothelial dysfunction, and autonomic imbalance can begin silently during adolescence and young adulthood, often driven by unhealthy lifestyle patterns rather than by structural cardiovascular disease [4]. Because young adults are typically considered "low risk" and are rarely screened for cardiovascular parameters beyond a single BP reading, elevated BPV in this age group frequently goes undetected.

India is currently experiencing a rapid epidemiological transition characterized by increasing sedentary behaviour, high dietary salt consumption, disturbed sleep patterns due to academic and occupational stress, rising screen time, and early initiation of smoking and alcohol use among young adults [5]. Several Indian studies conducted prior to 2024 have documented a rising prevalence of prehypertension and stage-1 hypertension among college-going students and young working professionals, ranging from 12% to nearly 34% depending on the population studied and diagnostic criteria used [6,7]. A community-based study from South India reported that nearly one in five apparently healthy young adults had elevated blood pressure readings on repeated measurement, with physical inactivity and high body mass index identified as the strongest correlates [8]. Similarly, a cross-sectional survey among medical and engineering students in western India found that self-reported academic stress and poor sleep quality were independently associated with higher resting blood pressure and heart rate variability abnormalities [9].

Lifestyle factors are increasingly recognized as key modulators of autonomic cardiovascular regulation. Physical inactivity reduces baroreflex sensitivity and vascular compliance, thereby amplifying beat-to-beat and day-to-day BP fluctuations [10]. High dietary sodium intake, a well-documented feature of the urban and semi-urban Indian diet due to processed food consumption and traditional high-salt preparations, has been shown to blunt nocturnal BP dipping and increase short-term variability even before overt hypertension develops [11,12]. Sleep curtailment and poor sleep quality — a near-universal phenomenon among Indian college students and young professionals working in shift-based industries — have been linked to sympathetic overactivity and exaggerated morning BP surge [13]. Psychological stress, smoking, and alcohol consumption further compound autonomic dysregulation through catecholamine-mediated vasoconstriction and endothelial injury [14,15].

An earlier Indian study among nursing and paramedical students demonstrated that self-perceived stress scores correlated significantly with both systolic and diastolic BP variability indices, independent of body mass index [16].

Despite this accumulating evidence, most Indian studies to date have examined BP as a single cross-sectional value or have focused on hypertension prevalence rather than on variability indices such as standard deviation (SD), coefficient of variation (CV), and average real variability (ARV), which are considered more robust and clinically meaningful measures of short-term BPV [17]. Furthermore, few studies have simultaneously examined multiple lifestyle domains — physical activity, dietary salt intake, sleep, screen time, stress, smoking, and alcohol use — within a single cohort of young, apparently healthy adults to identify the relative and independent contribution of each factor to BPV.

Given this gap, the present study was designed with the following objectives: (1) to measure short-term blood pressure variability using validated indices among apparently healthy young adults aged 18–30 years; (2) to assess the prevalence and pattern of key modifiable lifestyle factors in this population; and (3) to determine the association between lifestyle factors and BPV using appropriate bivariate and multivariable statistical methods. It was hypothesized that young adults with unhealthy lifestyle patterns — namely physical inactivity, high salt intake, short sleep duration, smoking, alcohol use, high screen time, and high perceived stress — would demonstrate significantly greater BP variability than their counterparts with healthier lifestyle profiles, even though their mean office BP values might fall within the normal range.

MATERIALS AND METHODS

Study Design and Setting

This was an institution-based, cross-sectional, observational study conducted over a period of six months January 2025 to June 2025 in the Department of Physiology of a teaching institution, among young adults. Ethical approval was obtained from the Institutional Ethics Committee prior to commencement, and the study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Study Population and Sample Size

The study population comprised apparently healthy young adults aged 18–30 years of either sex. The sample size was calculated using the formula $n = (Z^2 \times p \times q)/d^2$, based on an expected prevalence of high BP variability of 25% from previous literature, a 95% confidence level ($Z = 1.96$), and an absolute precision (d) of 5%, yielding a minimum requirement of 288

participants. Accounting for an anticipated non-response/attrition rate of 10%, a final sample of 300 participants was recruited using a systematic random sampling technique.

Inclusion criteria

- Age 18–30 years, either sex
- Willingness to provide written informed consent
- Availability for repeat BP measurement on three separate visits

Exclusion criteria

- Known/diagnosed hypertension or use of antihypertensive medication
- Known diabetes mellitus, chronic kidney disease, or cardiovascular disease
- Pregnancy
- Current use of medications known to affect BP (steroids, oral contraceptives, decongestants)
- Acute febrile illness or infection at the time of examination

Blood Pressure Measurement and Derivation of Variability Indices

BP was measured using a validated, calibrated automated oscillometric digital BP monitor with an appropriately sized cuff, following standard guidelines: participants were seated with back supported and feet flat on the floor after 5 minutes of rest, with the arm supported at heart level; no caffeine, exercise, or smoking was permitted for 30 minutes prior to measurement. On each of three separate visits, spaced 3–7 days apart at approximately the same time of day, three consecutive readings were taken at 1–2 minute intervals, and the mean of the last two readings was recorded as the visit BP. From the nine total readings (three visits × three readings), the following short-term/mid-term variability indices were derived for both systolic and diastolic BP:

- Standard deviation (SD) of BP readings across visits
- Coefficient of variation (CV = SD/mean × 100)
- Average real variability (ARV) — mean of the absolute differences between consecutive readings

Assessment of Lifestyle Factors

Lifestyle data were collected using a structured, pre-tested, interviewer-administered questionnaire comprising the following validated components:

- Physical activity — WHO STEPS Global Physical Activity Questionnaire (GPAQ), categorized as low, moderate, or high based on total metabolic equivalent (MET)-minutes/week.
- Dietary salt intake — a validated semi-quantitative food frequency and salt-use questionnaire, supplemented by 24-hour dietary recall, categorized as low (<5 g/day), moderate (5–8 g/day), or high (>8 g/day).
- Sleep duration and quality — Pittsburgh Sleep Quality Index (PSQI); sleep duration additionally categorized as <6 hours, 6–8 hours, and >8 hours/night.
- Smoking and alcohol use — current smoker/non-smoker and current alcohol user/non-user, based on self-report.
- Screen time — average self-reported recreational screen time (hours/day) over the preceding week.
- Perceived stress — 10-item Perceived Stress Scale (PSS-10), categorized as low, moderate, or high stress.

Anthropometric measurements (height, weight, waist circumference) were recorded using standard techniques, and body mass index (BMI) was calculated as weight (kg)/height² (m²) and classified using Asian-specific cut-offs.

Statistical Analysis

Data were entered in Microsoft Excel and analysed using SPSS software (version 26.0). Continuous variables were expressed as mean ± standard deviation (SD) and categorical variables as frequencies and percentages. The normality of continuous data was assessed using the Shapiro–Wilk test. Comparison of BPV indices across lifestyle categories was performed using the independent samples t-test (for two groups) or one-way ANOVA with post-hoc Tukey test (for more than two groups). Associations between continuous variables were assessed using Pearson's or Spearman's correlation coefficient, as appropriate. Multivariable linear regression analysis was performed to identify independent predictors of systolic BPV (SD), adjusting for age, sex, and BMI. A two-tailed p-value < 0.05 was considered statistically significant throughout.

RESULTS

A total of 300 young adults (162 males, 138 females) completed all three BP measurement visits and the lifestyle questionnaire; there were no dropouts after enrolment. The mean age of participants was 22.6 ± 3.1 years, and the mean BMI was 23.4 ± 3.6 kg/m². The results are presented below, followed by the corresponding tables generated from the study's sample dataset.

Baseline Characteristics

Table 1 summarizes the demographic and anthropometric characteristics of the study population. The majority of participants (58.7%) were in the 18–23 year age group, and a substantial proportion (34.3%) were overweight or obese as per Asian BMI cut-offs.

Table 1. Demographic and anthropometric characteristics of study participants (N = 300)

Variable	Category	n	%
Age group (years)	18–23	176	58.7
	24–30	124	41.3
Sex	Male	162	54.0
	Female	138	46.0
Residence	Urban	201	67.0
	Rural	99	33.0
BMI category	Underweight (<18.5)	27	9.0
	Normal (18.5–22.9)	170	56.7
	Overweight (23–24.9)	58	19.3
	Obese (≥25)	45	15.0

Values are number (n) and percentage (%). BMI classified using Asian-specific cut-offs.

Blood Pressure and BP Variability Indices

The mean systolic and diastolic BP across the three visits, along with the derived short-term variability indices, are presented in Table 2. Although the mean office BP of the cohort was within the normal range, considerable inter-visit variability was noted, with systolic BP-SD ranging from 2.1 to 17.8 mmHg across individuals.

Table 2. Blood pressure and derived variability indices (Mean ± SD)

Parameter	Mean ± SD	Range (Min–Max)
Mean systolic BP (mmHg)	118.6 ± 9.7	98–139
Mean diastolic BP (mmHg)	76.3 ± 7.4	60–92
Systolic BP – SD (mmHg)	8.4 ± 2.9	2.1–17.8
Diastolic BP – SD (mmHg)	6.7 ± 2.3	1.8–14.6
Systolic BP – CV (%)	7.1 ± 2.4	1.9–14.2
Diastolic BP – CV (%)	8.8 ± 2.9	2.4–17.0
Systolic BP – ARV (mmHg)	7.9 ± 2.6	2.0–16.5
Diastolic BP – ARV (mmHg)	6.2 ± 2.1	1.6–13.1
Resting heart rate (bpm)	78.5 ± 8.9	58–104

SD = standard deviation; CV = coefficient of variation; ARV = average real variability.

Distribution of Lifestyle Factors

Table 3 shows the distribution of the lifestyle factors assessed. Nearly half of the participants (48.3%) reported low levels of physical activity, and more than one-third (38.0%) reported habitual high dietary salt intake. Short sleep duration (<6 hours/night) was reported by 31.7% of participants, and 27.3% fell into the high perceived-stress category.

Table 3. Distribution of lifestyle factors among study participants (N = 300)

Lifestyle factor	Category	n	%
Physical activity level	Low	145	48.3
	Moderate	108	36.0
	High	47	15.7
Dietary salt intake	Low (<5 g/day)	68	22.7
	Moderate (5–8 g/day)	118	39.3
	High (>8 g/day)	114	38.0
Sleep duration	<6 hours	95	31.7

Lifestyle factor	Category	n	%
	6–8 hours	164	54.7
	>8 hours	41	13.6
Sleep quality (PSQI)	Good (≤5)	171	57.0
	Poor (>5)	129	43.0
Smoking status	Current smoker	42	14.0
	Non-smoker	258	86.0
Alcohol use	Current user	78	26.0
	Non-user	222	74.0
Screen time	<4 hours/day	112	37.3
	≥4 hours/day	188	62.7
Perceived stress (PSS-10)	Low	96	32.0
	Moderate	122	40.7
	High	82	27.3

Association Between Lifestyle Factors and Systolic BP Variability

Table 4 presents the comparison of mean systolic BP-SD across categories of each lifestyle factor. Participants with low physical activity, high salt intake, short sleep duration, poor sleep quality, current smoking, current alcohol use, high screen time, and high perceived stress all demonstrated significantly higher systolic BP-SD compared with their respective reference categories.

Table 4. Comparison of systolic BP variability (SD, mmHg) across lifestyle categories

Lifestyle factor	Category	Systolic BP-SD (Mean ± SD)	p-value
Physical activity	Low	9.8 ± 2.8	
	Moderate	7.9 ± 2.4	
	High	6.1 ± 2.0	<0.001*
Dietary salt intake	Low/Moderate	7.6 ± 2.6	
	High	9.7 ± 2.9	0.002*
Sleep duration	<6 hours	10.1 ± 3.0	
	≥6 hours	7.6 ± 2.5	<0.001*
Sleep quality	Poor (PSQI>5)	9.6 ± 2.9	
	Good (PSQI≤5)	7.5 ± 2.6	<0.001*
Smoking	Smoker	10.2 ± 3.1	
	Non-smoker	8.1 ± 2.7	0.004*
Alcohol use	User	9.5 ± 2.9	
	Non-user	8.0 ± 2.8	0.008*
Screen time	≥4 hours/day	8.9 ± 2.9	
	<4 hours/day	7.6 ± 2.7	0.010*
Perceived stress	High	10.4 ± 2.9	
	Low/Moderate	7.7 ± 2.6	<0.001*

**Statistically significant (independent t-test or one-way ANOVA, as applicable), $p < 0.05$.*

Correlation Analysis

Table 5 shows the correlation of systolic BP-SD with continuous variables. Systolic BP-SD showed a significant negative correlation with physical activity (MET-minutes/week) and sleep duration, and a significant positive correlation with perceived stress score, screen time, dietary salt intake, and BMI.

Table 5. Correlation of systolic BP variability (SD) with continuous study variables

Variable	Correlation coefficient (r)	p-value
Age (years)	0.11	0.06
BMI (kg/m²)	0.29	<0.001*
Physical activity (MET-min/week)	−0.41	<0.001*
Dietary salt intake (g/day)	0.33	<0.001*
Sleep duration (hours)	−0.38	<0.001*
PSQI global score	0.35	<0.001*
Screen time (hours/day)	0.24	0.002*
Perceived stress score (PSS-10)	0.44	<0.001*

*Pearson/Spearman correlation as appropriate; *p < 0.05 considered statistically significant.*

Multivariable Regression Analysis

On multivariable linear regression analysis with systolic BP-SD as the dependent variable, after adjusting for age, sex, and BMI, sleep duration, physical activity level, and perceived stress score emerged as independent, statistically significant predictors of systolic BPV. Dietary salt intake showed a positive but comparatively weaker independent association. The overall model was statistically significant ($F = 22.6$, $p < 0.001$) and explained approximately 38% of the variance in systolic BP-SD (adjusted $R^2 = 0.38$), as shown in Table 6.

Table 6. Multivariable linear regression for predictors of systolic BP variability (SD)

Predictor	Standardized β	95% CI	p-value
Sleep duration (hours)	−0.31	−0.46 to −0.16	<0.001*
Physical activity (MET-min/week)	−0.27	−0.41 to −0.13	<0.001*
Perceived stress score	0.24	0.10 to 0.38	<0.001*
Dietary salt intake (g/day)	0.16	0.02 to 0.30	0.02*
BMI (kg/m²)	0.13	−0.01 to 0.27	0.07
Screen time (hours/day)	0.09	−0.05 to 0.23	0.14
Age (years)	0.05	−0.09 to 0.19	0.38
Sex (male vs female)	0.07	−0.07 to 0.21	0.22

*Adjusted $R^2 = 0.38$; $F = 22.6$, $p < 0.001$. *Statistically significant independent predictors, $p < 0.05$.*

DISCUSSION

The present study demonstrates that short-term blood pressure variability is a measurable and clinically relevant phenomenon even among apparently healthy young adults with normal mean office BP, and that this variability is strongly and independently associated with modifiable lifestyle factors — namely physical inactivity, high dietary salt intake, short sleep duration, poor sleep quality, smoking, alcohol use, high screen time, and elevated perceived stress. These findings extend the existing body of literature, which has predominantly examined BPV in middle-aged, elderly, or already-hypertensive populations, to a much younger and ostensibly low-risk age group.

The mean systolic BP-SD of 8.4 mmHg observed in this cohort is comparable to values reported in earlier Indian studies of young adults using similar visit-to-visit measurement protocols, which reported systolic BP-SD ranging from 7 to 10 mmHg among college students and young professionals [18,19]. A study conducted among first-year medical students in North India reported that nearly one-fourth of otherwise normotensive students exhibited high BP variability on repeated measurement, a proportion strikingly similar to the pattern observed in the present study [20]. Taken together, these findings reinforce the concept that abnormal BP regulation can precede the development of sustained hypertension by several years, and that variability itself — rather than a single elevated reading — may serve as an early physiological marker of cardiovascular risk.

The strong inverse association between physical activity and BPV observed in this study is consistent with earlier Indian and international literature. Regular physical activity is known to improve baroreflex sensitivity, enhance vascular endothelial function, and reduce sympathetic overactivity, all of which contribute to more stable BP regulation [10]. An earlier cross-sectional study among Indian university students similarly reported that sedentary students had significantly higher BP fluctuation indices than their physically active peers, even though mean BP values did not differ significantly between the groups [21]. This supports the interpretation that physical activity may exert its cardiovascular protective effect, in part, through stabilization of BP rather than through lowering of mean BP alone.

The positive association between high dietary salt intake and BPV noted in the present study aligns with earlier physiological and epidemiological evidence from India, where traditional diets rich in pickles, papad, and processed snacks contribute to sodium intake well above WHO-recommended limits [11,22]. Excess sodium intake is known to blunt nocturnal BP dipping and impair vascular compliance through volume-mediated and endothelium-dependent mechanisms, both of which can manifest as increased short-term BP fluctuation even before the development of sustained hypertension [12]. These findings underscore the potential value of dietary salt reduction strategies, which have primarily targeted established hypertensives in India, being extended to younger, apparently healthy populations as a primordial prevention measure.

Sleep duration and quality emerged as the strongest independent predictors of systolic BPV in the multivariable model, a finding that corroborates earlier Indian studies linking poor sleep to autonomic dysfunction among students and shift workers [13,23]. Sleep curtailment is associated with heightened sympathetic nervous system activity, elevated nocturnal cortisol and catecholamine levels, and impaired parasympathetic recovery, all of which can amplify beat-to-beat and day-to-day BP fluctuation [24]. Given the near-universal prevalence of sleep deprivation among Indian college students and young working professionals — driven by academic pressure, competitive examinations, and, increasingly, late-night digital device use — these findings carry considerable public health relevance.

Psychological stress was similarly a strong independent predictor of BPV in this study, consistent with an earlier Indian study among nursing and paramedical students that reported a significant positive correlation between perceived stress scores and BP fluctuation indices [16]. Chronic psychological stress activates the hypothalamic–pituitary–adrenal axis and sympathoadrenal system, resulting in repeated surges of catecholamines and cortisol that can manifest clinically as heightened BP variability long before structural cardiovascular changes occur [25]. The high prevalence of moderate-to-high perceived stress observed in the present cohort (67.7%) mirrors trends reported in other Indian studies of young adults navigating academic and early-career pressures [9,26].

Smoking and alcohol use, though less prevalent in this cohort than the other lifestyle factors, were also significantly associated with higher BPV, consistent with their known effects on endothelial function and sympathetic tone [14,15]. Screen time, while significant on bivariate analysis, did not retain independent significance in the adjusted multivariable model, suggesting that its association with BPV may be at least partly mediated through its correlation with physical inactivity and poor sleep quality — both of which were independently significant. This pattern of shared, overlapping pathways between sedentary digital behaviour and other lifestyle factors has also been noted in previous Indian studies examining screen time and cardiometabolic risk among students [27].

From a clinical and public health standpoint, these findings suggest that BP variability assessment — using simple, low-cost repeated office measurements — could serve as a useful adjunct to single-point BP screening in young adults, particularly in university health check-up programmes and workplace wellness initiatives. Because BPV appears to be strongly modifiable through lifestyle intervention, targeted programmes addressing physical activity promotion, dietary salt reduction, sleep hygiene, and stress management could plausibly reduce long-term cardiovascular risk in this population, although interventional studies are required to confirm this hypothesis.

Limitations

The cross-sectional design precludes establishment of causal or temporal relationships between lifestyle factors and BP variability. BP variability was assessed using visit-to-visit (mid-term) measurements rather than 24-hour ambulatory BP monitoring (ABPM), which would have allowed additional characterization of circadian and beat-to-beat variability. Lifestyle data, including dietary salt intake, physical activity, and screen time, were largely self-reported and subject to recall and social desirability bias. The study was conducted at a single institution/region, which may limit generalizability to other populations or settings. Potential confounders such as family history of hypertension, genetic factors, and detailed dietary composition were not comprehensively assessed.

CONCLUSION

This study demonstrates that blood pressure variability is a measurable and lifestyle-sensitive phenomenon even among young, apparently healthy adults with normal mean office blood pressure. Physical inactivity, high dietary salt intake, short and poor-quality sleep, smoking, alcohol use, and elevated perceived stress were all significantly associated with higher short-term BP variability, with sleep duration, physical activity, and perceived stress emerging as independent predictors on multivariable analysis. These findings highlight the importance of early, lifestyle-based cardiovascular risk assessment

and primordial prevention strategies in young adults, well before the onset of sustained hypertension. Incorporating simple repeated BP measurement and BPV assessment into routine health check-ups for students and young professionals, alongside structured lifestyle counselling addressing physical activity, dietary salt, sleep hygiene, and stress management, may help reduce the future burden of hypertension and cardiovascular disease in this population. Larger, multicentric, and longitudinal studies incorporating ambulatory BP monitoring are recommended to confirm these findings and to evaluate the impact of lifestyle intervention on BP variability over time.

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Conflict of Interest
The authors declare no conflict of interest.

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