



ASSOCIATION OF SYMPATHOVAGAL IMBALANCE WITH MYOCARDIAL WORK STRESS AND ATHEROGENIC INDEX IN PREHYPERTENSION

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Abstract

Background: Prehypertension is an early high blood pressure phenotype associated with cardiovascular risk; however, the relationship between cardiac autonomic derangements, atherogenic index, and myocardial work stress remains unclear in younger adults. Therefore, in this study, we evaluated the association between HRV-derived cardiac autonomic modulation and the atherogenic index of plasma and rate pressure product in individuals with prehypertension.

Methods: This cross-sectional study was conducted on apparently healthy adults aged between 18-30 years, comprising 44 prehypertensive individuals and 44 normotensive individuals as controls. Anthropometric variables, resting cardiac parameters, heart rate variability, rate pressure product, fasting lipid profile, and atherogenic index of plasma were assessed. Between-group comparisons and correlation analyses were performed using appropriate statistical tests.

Results: Higher body weight, body mass index, heart rate, blood pressure, and rate pressure product were observed in prehypertensive individuals. In comparison to normotensive controls, prehypertensive individuals had higher LFnu and LF/HF ratio, and lower total power, SDNN, RMSSD, HF power, and HFnu. The lipid profile showed lower HDL cholesterol and higher total cholesterol, triglycerides, LDL cholesterol, VLDL cholesterol, and atherogenic index of plasma. Furthermore, the LF/HF ratio was positively correlated with the rate pressure product and atherogenic index of plasma and negatively correlated with HDL cholesterol.

Conclusion: Young adults with prehypertension demonstrate altered cardiac autonomic modulation associated with increased myocardial work stress and atherogenic lipid risk, supporting the need for early cardiovascular risk assessment.

Key words: Prehypertension, Heart rate variability, sympathovagal imbalance, cardiac autonomic modulation, rate-pressure product, myocardial work stress, atherogenic index.

Introduction

Prehypertension (PreHTN) was defined in the Seventh Report of the Joint National Committee as a systolic blood pressure of 120–139 mmHg and/or diastolic blood pressure of 80–89 mmHg, representing an intermediate blood pressure phenotype between normotension and established hypertension(1). Although the later ACC/AHA guidelines reorganized these blood pressure strata into elevated blood pressure and stage 1 hypertension, the earlier JNC-7 category remains clinically and epidemiologically relevant because it identifies individuals who are not yet conventionally hypertensive but already show increased cardiovascular risk (2). Large-scale epidemiological evidence demonstrates that vascular risk increases progressively across the blood pressure distribution without a clear biological threshold within the conventionally “normal” range(3). Meta-analytic evidence further indicates that individuals with prehypertensive blood pressure levels have a higher risk of incident cardiovascular disease and stroke than those with optimal blood pressure(4). The public health relevance of early blood pressure dysregulation is particularly important in India, where hypertension has emerged as a major contributor to cardiovascular morbidity and mortality in the country. A systematic review and meta-analysis reported a substantial burden of hypertension among Indian adults, with marked urban–rural variations and suboptimal awareness, treatment, and control(5). Importantly, elevated blood pressure phenotypes are increasingly recognized in young adults, often clustering with excess body weight and dyslipidemia. In young Indian military adults, prehypertension was reported to be highly prevalent and associated with being overweight and adverse lipid parameters(6). These observations suggest that prehypertension should not be viewed as an isolated hemodynamic abnormality but rather as an early cardiometabolic risk state. Autonomic nervous system dysregulation is a plausible mechanism linking early blood pressure elevation to cardiovascular risk. Heart rate variability is a non-invasive tool used to assess cardiac autonomic modulation, with time- and frequency-domain indices reflecting different aspects of sinus node regulation (7,8). However, the interpretation of the LF/HF ratio requires caution; although it has been widely used as an operational index of sympathovagal modulation, it should not be treated as a direct quantitative measure of sympathetic-vagal balance(9). Nevertheless, studies in Indian populations have shown altered HRV patterns in prehypertensive individuals, including reduced vagal modulation and relatively increased sympathetic modulation(10). Recent evidence also supports the concept that prehypertension coexists with autonomic and metabolic dysfunction, particularly in relation to systolic blood pressure and lipid metabolism(11).

Beyond blood pressure elevation, myocardial workload may provide additional insight into early cardiovascular stress. The rate-pressure product, calculated as the heart rate multiplied by the systolic blood pressure, is a practical hemodynamic surrogate of myocardial oxygen demand and has been described as a determinant of cardiovascular risk in hypertension(12). Because both heart rate and systolic blood pressure are influenced by autonomic regulation, an increase in the rate-pressure product in prehypertensive individuals may reflect the functional consequence of altered cardiac autonomic modulation. Therefore, examining the association between HRV-derived autonomic indices and the rate-pressure product may help clarify whether early autonomic dysregulation is linked to increased myocardial work stress before the onset of overt hypertension.

Dyslipidemia is another major pathway through which prehypertension may contribute to vascular risk. The atherogenic index of plasma, calculated as $\log(\text{TG}/\text{HDL-C})$, integrates the relationship between triglyceride-rich lipoproteins and HDL cholesterol and has been shown to correlate with lipoprotein particle size and plasma atherogenicity(13). Subsequent studies have demonstrated that the atherogenic index of plasma correlates with lipoprotein size and coronary angiographic findings, supporting its relevance as a marker of atherogenic risk(14). Associations between atherogenic indices and prehypertensive blood pressure patterns have also been reported, suggesting that lipid-derived vascular risk may be present even before the clinical diagnosis of hypertension(15).

Taken together, the available evidence indicates that prehypertension is associated with an elevated cardiovascular risk, altered cardiac autonomic modulation, increased myocardial workload, and adverse lipid-related risks. However, the interrelationship between HRV-derived autonomic

imbalance, rate-pressure product, and atherogenic index of plasma remains insufficiently characterized in young prehypertensive individuals. Therefore, the present study was designed to evaluate the association between sympathovagal imbalance, myocardial work stress, and atherogenic risk among individuals with prehypertensive blood pressure levels.

Material and methods

Study Design and Setting: This cross-sectional analytical study was conducted at the Department of Physiology and Multidisciplinary Research Unit, Sri Venkateswara Medical College, Tirupati, Andhra Pradesh, India.

Study Participants: Apparently healthy male and female individuals aged 18–30 years were recruited from medical college students and community volunteers. A total of 88 participants were enrolled and categorized into two groups: normotensive controls and individuals with prehypertension, with 44 participants in each group. The control group included apparently healthy individuals with systolic blood pressure between 100 and 119 mmHg and diastolic blood pressure between 60 and 79 mmHg. The prehypertensive group included apparently healthy individuals with systolic blood pressure between 120 and 139 mmHg and/or diastolic blood pressure between 80 and 89 mmHg. Participants receiving any medication and those with a history of diabetes mellitus, established hypertension, endocrine disorders, renal disease, known cardiovascular disease, or any other systemic illnesses were excluded. Individuals already receiving antihypertensive medications were also excluded.

Ethical Considerations: The study was approved by the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrolment. All study procedures were performed in accordance with the ethical principles for human participant research. Participant confidentiality was maintained throughout the data collection, analysis, and reporting processes.

Pre-assessment Standardization: Participants were instructed to refrain from heavy physical activity for 24 h before the autonomic function assessment. All recordings were performed in a quiet laboratory with subdued lighting. The ambient temperature of the laboratory was maintained between 25°C and 28°C. Participants were asked to void urine before testing and were allowed to sit comfortably in the laboratory to acclimatize to the environment before baseline measurements were taken.

Anthropometric Assessment: Baseline demographic and anthropometric parameters, including age, sex, height, and weight were recorded using standard procedures. Body mass index was calculated as weight in kilograms divided by height in meters squared and expressed as kg/m².

Resting Cardiovascular Assessment: Resting heart rate and blood pressure were recorded after the participants remained seated quietly for 10 min. Blood pressure was measured using the auscultatory method. Three consecutive blood pressure readings were obtained, and the mean of the three readings was used for analysis, provided that the difference between successive readings did not exceed 4 mmHg. The systolic blood pressure, diastolic blood pressure, and basal heart rate were recorded. The mean arterial pressure was calculated using the following formula:

Mean arterial pressure = Diastolic blood pressure + 1/3(Systolic blood pressure – Diastolic blood pressure)

The rate-pressure product was calculated as an index of myocardial work stress using the following formula:

Rate-pressure product = Heart rate × Systolic blood pressure

Heart Rate Variability Recording and Analysis: Cardiac autonomic modulation was assessed using short-term heart rate variability analysis. After the baseline cardiovascular assessment, the participants were placed in the supine position with eyes closed and instructed to remain relaxed

while breathing spontaneously at approximately 12–18 breaths per minute. A lead II electrocardiogram was recorded for 10 min. The ECG signal was obtained with an adequate amplitude and clear R-wave identification. The RR intervals were extracted from the ECG recordings. Artifacts and ectopic beats were excluded before the analysis. A stationary 256-second RR interval segment was selected for HRV analysis. HRV analysis was performed using the Kubios HRV Version 2.0 software. The RR interval series was resampled at 4 Hz, detrended, and processed after the removal of the mean and trend components. A Hann window was applied, and a 1024-point data series was transformed using Fast Fourier Transformation for frequency-domain analysis. The time-domain indices included the mean RR interval, standard deviation of normal-to-normal intervals, and root mean square of successive RR interval differences. The frequency-domain indices included very low frequency power, low frequency power, high frequency power, total power, normalized low frequency power, normalized high frequency power, and LF/HF ratio. HF power and HFnu were interpreted as indices that predominantly reflect parasympathetic cardiac modulation. LFnu and the LF/HF ratio were interpreted as HRV-derived indices of relative autonomic modulation. The LF/HF ratio was used operationally as an HRV-derived index of relative autonomic modulation and was not interpreted as a direct quantitative measure of sympathetic-vagal balance.

Blood Sampling and Biochemical Analysis: After overnight fasting, 5 mL of venous blood was collected from each participant under aseptic precautions. Blood samples were processed to estimate lipid profile parameters. Total cholesterol, triglyceride, HDL cholesterol, LDL cholesterol, and VLDL cholesterol levels were estimated using a Bio-Rad analyzer and Bio-Rad kits, according to the manufacturer's instructions.

The atherogenic index of plasma was calculated using the following formula:

Atherogenic index of plasma = $\log_{10}(\text{TG}/\text{HDL-C})$

Triglyceride and HDL cholesterol values were expressed in mmol/L for the calculation of the atherogenic index of plasma. When lipid values were obtained in mg/dL, they were converted to mmol/L before calculating the Atherogenic index.

Statistical Analysis: Statistical analysis was performed using R software version 3.2.3 for Windows. Continuous variables were examined for normality using the Kolmogorov–Smirnov test. Normally distributed variables are expressed as mean $\pm$ standard deviation, whereas non-normally distributed variables are expressed as median with interquartile range. Between-group comparisons were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Correlation analysis was performed to examine the association of the LF/HF ratio with the rate-pressure product, HDL cholesterol, and atherogenic index of plasma. Pearson's correlation coefficient was used for normally distributed variables, and Spearman's rank correlation coefficient was used for non-normally distributed variables. All statistical tests were performed using two-tailed tests. Statistical significance was set at $p \leq 0.05$.

Results

A total of 88 participants were included in the study, with 44 in the normotensive control group and 44 in the prehypertensive group. The general characteristics and anthropometric parameters of both groups are shown in Table 1.

There was no statistically significant difference in age between the control and prehypertensive groups, indicating that the two groups were comparable with respect to age. Similarly, height did not differ significantly between the control and prehypertensive groups, although the difference approached statistical significance.

However, body weight and body mass index were significantly higher in the prehypertension group than in the control group. BMI was significantly higher among prehypertensive participants than among controls.

The resting cardiovascular parameters differed significantly between the two groups. The basal heart rate was significantly higher in the prehypertensive group than in the control group. As expected from the grouping criteria, systolic and diastolic blood pressures were significantly higher in the prehypertensive group. The mean arterial pressure was also significantly higher among prehypertensive participants than in the controls. The rate-pressure product, used as an index of myocardial work stress, was significantly higher in the prehypertensive group than in the control group.

The HRV parameters are presented in Table 2. In the time-domain analysis, the mean RR interval did not differ significantly between the control and prehypertensive groups. However, SDNN was significantly lower in the prehypertensive group than in the control group. The RMSSD was also significantly reduced in the prehypertensive group, indicating reduced short-term beat-to-beat variability.

In the frequency-domain analysis, total power was significantly lower in the prehypertensive group than in the control group. Very-low-frequency power was also significantly reduced in the prehypertensive group. The absolute low-frequency power did not differ significantly between the groups. However, absolute high-frequency power was significantly lower in the prehypertensive group than in the control group.

The normalized low-frequency power was significantly higher in the prehypertensive group than in the control group, whereas the normalized high-frequency power was significantly lower. The LF/HF ratio, used as an HRV-derived index of relative autonomic modulation, was significantly higher in the prehypertensive group than in the control group.

A comparison of the lipid profile parameters between the control and prehypertensive groups is shown in Table 3. Total cholesterol was significantly higher in the prehypertensive group than in the control group. Triglyceride levels were also significantly higher in the prehypertensive group than in the control group.

HDL cholesterol was significantly lower in prehypertensive participants than in controls. LDL cholesterol levels were significantly elevated in the prehypertensive group. VLDL levels were also significantly higher among prehypertensive participants than in controls. The atherogenic index of plasma was significantly higher in the prehypertensive group than in the control group, indicating a greater lipid-derived atherogenic risk among participants with prehypertensive blood pressure levels. Correlation analysis was performed to evaluate the association of the LF/HF ratio with the rate-pressure product, HDL cholesterol, and atherogenic index of plasma in both groups. The results are shown in Table 4. In the control group, the LF/HF ratio was not significantly correlated with the rate-pressure product, HDL cholesterol or atherogenic index of plasma. In contrast, among prehypertensive participants, the LF/HF ratio showed a significant positive correlation with the rate-pressure product, indicating that greater relative autonomic imbalance was associated with increased myocardial work stress. The LF/HF ratio also showed a significant positive correlation with the atherogenic index of plasma and a significant negative correlation with HDL cholesterol. These findings suggest that altered HRV-derived autonomic modulation in prehypertensive individuals is associated with both increased myocardial workload and atherogenic lipid profiles.

Table 1: Comparison of parameters between controls and prehypertensives

Sl.No	Parameters	Controls	PreHTN	p value
General characteristics and anthropometric parameters				
1	Age (Yrs)	20.95±2.27	20.97±2.10	0.961
2	Height (cms)	160.06±7.21	158.90±7.49	0.057
3	Weight (Kg)	51.06±6.62	59.90±8.32	0.000
4	BMI (Kg/m ²)	19.96±2.52	24.49±4.12	0.000
Cardiovascular parameters				
1	BHR (beats/min)	70.65±5.17	79.43±4.66	0.000

2	SBP (mmHg)	110.65±5.43	128.45±6.47	0.000
3	DBP (mmHg)	67.13±6.20	81.04±4.22	0.000
4	MAP (mmHg)	81.64±4.69	96.84±3.32	0.000
5	RPP (mmHg/min)	7823±729	10206±835	0.000

Data are expressed as mean ± SD. BMI: Body mass index; BHR: Basal heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; RPP: Rate pressure product.

Table 2: Comparison of Heart rate variability parameters between controls and prehypertensives.

Sl.No	Parameters	Controls	PreHTN	p value
Time domain indices				
1	Mean RR (ms)	809 (745-939)	810 (732.27-866.62)	0.458
2	SDNN (ms)	31.35 (23.67-37.37)	22.90 (16.10-27.70)	0.000
3	RMSSD (ms)	27.40 (21.82-33.77)	19.20 (13.40-26.07)	0.000
Frequency domain indices				
1	VLF (ms ²)	261 (92.75-500.25)	47 (18-210)	0.000
2	LF (ms ²)	154 (109-245)	258 (69.50-379)	0.186
3	HF (ms ²)	269 (176-461)	112 (37-239)	0.000
4	TP (ms ²)	754 (454-1234)	525.50 (281-729)	0.001
5	LF:HF	0.66 (0.39-0.82)	1.80 (1.15-3.27)	0.000
6	LFnu	40 (28.47-45.15)	64.40 (53.50-75.30)	0.000
7	HFnu	60 (54.57-71.52)	35.60 (23.35-46.50)	0.000

Data expressed as Median (IQR). TP, total power; LFnu, normalized low-frequency power; HFnu, normalized high-frequency power; LF-HF ratio, ratio of low-frequency to high frequency power; RMSSD, the square root of the mean of the sum of the squares of the differences between adjacent NN intervals.

Table 3: Comparison of lipid profile parameters between controls and prehypertensives.

Sl.No	Parameters	Controls	PreHTN	p value
1	Total cholesterol (mg/dl)	167±27.48	207.84±33.96	0.000
2	Triglycerides (mg/dl)	155.06±25.55	171.75±34.95	0.012
3	HDL-cholesterol (mg/dl)	36.93±6.58	31.70±7.95	0.001
4	LDL-cholesterol (mg/dl)	99.05±28.93	141.78±35.62	0.000
5	VLDL-cholesterol (mg/dl)	31.01±5.11	34.35±6.99	0.012
6	Atherogenic Index of Plasma	0.62±0.10	0.74±0.14	0.000

Data are expressed as mean±SD.

Table 4: correlation of LF: HF ratio with RPP and atherogenic parameters

		Controls		PreHTN	
S.No	Parameters	r	p value	r	P value
1	RPP	0.188	0.221	0.646	0.000
2	HDL - C	-0.136	0.380	-0.700	0.000
3	AIP	0.071	0.648	0.696	0.000

RPP: Rate pressure product, AIP: Atherogenic index of plasma.

Discussion

The present study evaluated the association between HRV-derived relative autonomic modulation, myocardial work stress, and atherogenic lipid risk among young adults with prehypertensive blood pressure levels. The principal findings were that individuals with prehypertension had significantly higher body weight, body mass index, basal heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, and rate-pressure product than normotensive controls. They also demonstrated reduced HRV indices, suggestive of lower cardiac vagal modulation, together with higher LFnu, lower HFnu, and an increased LF/HF ratio. In addition, the prehypertensive group showed an adverse lipid profile characterized by higher total cholesterol, triglyceride, LDL cholesterol, VLDL, and atherogenic index of plasma, along with lower HDL levels. Importantly, within the prehypertensive group, the LF/HF ratio showed a significant positive correlation with the rate-pressure product and atherogenic index of plasma and a significant negative correlation with HDL cholesterol. These associations were not observed in the normotensive controls.

The clinical relevance of these findings lies in the concept that prehypertension is not merely a borderline blood pressure category but may represent an early haemodynamic and cardiometabolic risk state. The JNC-7 introduced the term prehypertension to identify individuals with systolic blood pressure (SBP) of 120–139 mmHg and/or diastolic blood pressure (DBP) of 80–89 mmHg, emphasizing early lifestyle intervention before the progression to established hypertension (16). Large prospective studies have shown that vascular mortality increases progressively with increasing blood pressure without a clear threshold within the conventionally normal range(3). Meta-analytic data have further demonstrated that prehypertension is associated with an increased incidence of cardiovascular disease and stroke (17). Therefore, the present findings support the view that young individuals with prehypertensive blood pressure levels may already exhibit early physiological and biochemical alterations relevant to future cardiovascular risks.

The significantly higher BMI observed in the prehypertensive group is consistent with earlier Indian studies reporting that prehypertension clusters with excess body weight, central adiposity, and adverse metabolic risk factors (18). In the present study, prehypertensive participants had a mean BMI within the upper-normal to overweight range, whereas the controls had a lower BMI. This difference is important because adiposity may influence blood pressure, autonomic modulation, insulin sensitivity, and lipid metabolism. Pal et al. reported that BMI contributes to sympathovagal imbalance in prehypertensive individuals and that autonomic imbalance in prehypertension is characterized by increased sympathetic activity and vagal inhibition (19). Thus, the higher BMI in the present prehypertensive group should be interpreted not merely as a demographic difference but as a potentially important biological contributor to the autonomic and metabolic phenotypes observed in this study.

Short-term HRV analysis is a noninvasive method for evaluating cardiac autonomic modulation. According to the Task Force standards, time-domain indices such as SDNN and RMSSD and frequency-domain indices such as HF power provide useful information regarding autonomic regulation of sinus rhythm (20). In the present study, SDNN and RMSSD were significantly reduced in prehypertensive participants, suggesting reduced overall beat-to-beat variability and diminished

short-term vagal modulation compared with normotensive participants. The significant reduction in HF power and HFnu further supports the reduced parasympathetic cardiac modulation. These findings are consistent with those of previous reports showing altered HRV patterns in prehypertensive individuals (10).

The higher LFnu and LF/HF ratio observed in the prehypertensive group suggests altered relative autonomic modulation. However, the interpretation of LF/HF ratio requires caution. Although LF/HF has historically been used as an index of sympathovagal balance, Billman critically demonstrated that LF/HF does not accurately quantify cardiac sympathetic-vagal balance in a direct physiological sense (9). Therefore, in the present study, LF/HF should be interpreted as an HRV-derived index of relative autonomic modulation, rather than a direct quantitative measure of sympathetic and parasympathetic outflow. With this limitation in mind, the observed HRV pattern is compatible with a shift toward reduced vagal modulation and greater sympathetic predominance in prehypertension.

The finding of an increased basal heart rate in prehypertensive participants further supports altered cardiovascular autonomic regulation. Resting heart rate is influenced by autonomic tone and is considered a hemodynamic marker relevant to cardiovascular risk. Grassi reported that supine heart rate may reflect interindividual differences in sympathetic tone (21). In the present study, increased basal heart rate occurred together with increased blood pressure and reduced vagal HRV indices, suggesting that prehypertension in these young adults may involve an integrated autonomic-hemodynamic phenotype rather than an isolated elevation of arterial pressure.

The rate-pressure product was significantly higher in the prehypertensive group. Because RPP is calculated as heart rate multiplied by systolic blood pressure, it reflects the combined effect of chronotropic drive and systolic pressure load. RPP has been used as a surrogate index of myocardial oxygen demand and myocardial work stress (12). White et al., emphasized the clinical relevance of heart rate and RPP as determinants of cardiovascular risk in hypertension. In the present study, the positive correlation between the LF/HF ratio and RPP among prehypertensive participants suggests that altered HRV-derived autonomic modulation is associated with a higher myocardial workload even before the development of established hypertension. This finding is consistent with that of Pal et al., who reported that cardiovascular risks in young prehypertensive individuals were linked to sympathovagal imbalance and that autonomic indices predicted RPP (22).

The lipid profile findings indicate that prehypertensive participants had a more atherogenic biochemical phenotype than normotensive participants. Total cholesterol, triglycerides, LDL cholesterol, VLDL cholesterol, and AIP were significantly higher, whereas HDL cholesterol was significantly lower in the prehypertensive group. These findings are biologically plausible because prehypertension often clusters with obesity, insulin resistance, dyslipidemia, and early vascular dysfunction (23). In a study of first-degree relatives of patients with type 2 diabetes, Pal et al. reported that sympathovagal imbalance contributed to prehypertension and cardiovascular risks associated with insulin resistance, dyslipidemia, inflammation, and oxidative stress (24). Although the present study did not measure insulin resistance, inflammatory markers, or oxidative stress, the observed association of the LF/HF ratio with HDL cholesterol and AIP suggests a possible autonomic-metabolic link in young prehypertensive individuals.

AIP, calculated as $\log_{10}(\text{TG}/\text{HDL-C})$, provides an integrated estimate of lipid-related atherogenicity in the general population. Dobiášová and Frohlich showed that AIP correlates with lipoprotein particle size and cholesterol esterification rate, supporting its use as a marker of plasma atherogenicity (14). Later studies demonstrated that AIP and cholesterol esterification measures correlate with lipoprotein size and coronary angiographic findings (25). The present study found significantly higher AIP values in the prehypertensive group and a strong positive correlation between the LF/HF ratio and AIP in prehypertensive participants. This finding suggests that altered cardiac autonomic modulation may coexist with increased atherogenic lipid risk in the early stage of blood pressure dysregulation.

The negative correlation between the LF/HF ratio and HDL cholesterol levels in prehypertensive individuals is also clinically relevant. HDL cholesterol has traditionally been considered protective

in cardiovascular risk assessment, and lower HDL levels are commonly associated with insulin resistance, adiposity, and atherogenic dyslipidemia. In the present study, the inverse association between the LF/HF ratio and HDL cholesterol suggests that individuals with greater relative autonomic imbalance have lower HDL cholesterol. This does not establish a causal relationship, but it supports the hypothesis that autonomic dysregulation and dyslipidemia may be interrelated components of early cardiometabolic risk.

The integrated interpretation of the present findings is that young adults with prehypertension may exhibit a linked autonomic, hemodynamic, and atherogenic phenotype. Reduced vagal modulation and altered autonomic balance may contribute to higher resting heart rate and blood pressure, thereby increasing myocardial work stress. Simultaneously, an increased BMI and adverse lipid parameters may contribute to atherogenic risk. The correlations of the LF/HF ratio with RPP, HDL cholesterol, and AIP in the prehypertensive group support the possibility that cardiac autonomic dysregulation is associated with both myocardial workload and lipid-derived vascular risk. However, because this study was cross-sectional, these relationships should be interpreted as associations rather than evidence of causation.

The present findings have potential implications for prevention. As the participants were young adults, the observed autonomic and lipid abnormalities may represent early modifiable risk signals. Prehypertension provides a clinically useful window for intervention before the progression to sustained hypertension and overt cardiovascular disease. Lifestyle-based strategies targeting body weight, physical activity, diet quality, sleep, and stress may be particularly relevant for this population. However, interventional studies are required to determine whether improving autonomic modulation can reduce RPP, improve AIP, and delay the progression from prehypertension to hypertension.

This study had several strengths. We examined young adults, a population in which early cardiovascular risk detection may have long-term preventive value. Integrated autonomic, hemodynamic, and lipid-derived risk markers rather than evaluating blood pressure alone. HRV assessment was conducted using a standardized short-term ECG-based protocol, and lipid parameters were measured after overnight fast. AIP was calculated using triglyceride and HDL cholesterol values expressed in mmol/L, which is methodologically appropriate for this calculation.

This study also had some limitations. Since its cross-sectional design prevents causal inferences. BMI was significantly higher in the prehypertensive group, which may have contributed to both autonomic and lipid differences. Future studies should perform BMI-adjusted-and waist circumference-adjusted analyses. We did not assess insulin resistance, inflammatory markers, oxidative stress markers, catecholamines, baroreflex sensitivity, endothelial function, or arterial stiffness, all of which could provide mechanistic insights. The sample size was modest, and participants were recruited from medical college students and community volunteers, which may limit generalizability. Finally, longitudinal follow-up was not performed; therefore, it remains unknown whether the observed autonomic and atherogenic abnormalities predict the progression to hypertension or clinical cardiovascular events.

Conclusion

This study demonstrated that young adults with prehypertensive blood pressure levels exhibit reduced HRV indices, suggestive of lower vagal modulation, a higher rate-pressure product, an adverse lipid profile, and an increased atherogenic index of plasma. The significant correlations of the LF/HF ratio with the RPP, HDL cholesterol, and AIP in the prehypertensive group suggest that altered HRV-derived relative autonomic modulation is associated with both myocardial work stress and lipid-derived atherogenic risk. These findings support the need for early cardiovascular risk assessment and preventive lifestyle strategies in individuals with prehypertension blood pressure levels.

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Conflict of interest:

Nil

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