Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

Anthropometric And Functional Predictors of Cardiovascular Stress – A Cross-Sectional Study to Assess Their Association Across Normotensives, Pre-Hypertensives and Hypertensives in South India.

Dr. Meena Andiappan[1*], Dr. Ezhilnila Subramanian[2], Dr Radhakrishnan A[3], Dr. Brinda Srinivasagopalane[4]

[1]Associate Professor, Department of Physiology, Bhaarath Medical College and Hospital, Bharath Institute of Higher Education and Research (BIHER), Chennai, Tamil Nadu, India.

[2]Associate Professor, Department of Physiology, Dhanalakshmi Srinivasan Medical College and Hospital, Perambalur, Tamil Nadu, India,

[3]Associate professor, Department of community medicine, Indira Medical College and hospital, Thiruvallur, India,

[4]Professor, Chettinad Hospital and Research Institute, Kanchipuram, Tamil Nadu, India,

Corresponding Author:

Dr. Meena Andiappan, Associate Professor, Department of Physiology, Bhaarath Medical College and Hospital, Bharath Institute of Higher Education and Research (BIHER), Chennai, Tamil Nadu, India.

(Received: 05 December 2025 Revised: 15 January 2026 Accepted: 10 February 2026)

KEYWORDS

Anthropometric, rate pressure product, pulse respiratory quotient, body mass index, hypertensives.

ABSTRACT:

Background:

Hypertension, one of the most prevalent non-communicable diseases globally, contributes substantially to cardiovascular morbidity and mortality. Overweight and obesity amplify cardiovascular risk through activation of sympathetic and renin-angiotensin pathways, creating a metabolic environment that accelerates vascular and myocardial damage. The Rate Pressure Product (RPP)—a product of heart rate and systolic blood pressure—serves as a non-invasive index of myocardial oxygen consumption and overall cardiac workload. Meanwhile, the Pulse Respiration Quotient (PRQ), representing the ratio of pulse rate to respiratory rate, reflects cardiorespiratory coupling and autonomic balance. Exploring the interrelationship between anthropometric indices and these physiological parameters may provide valuable insight into cardiovascular stress across varying blood pressure categories.

Methods:

A cross-sectional observational study was conducted among 140 participants aged 30 years and above who were either newly diagnosed with hypertension or known hypertensives on treatment. A structured questionnaire was administered to document the demographic details, lifestyle factors and other clinical background. Anthropometric measurements were performed using WHO guidelines. Resting heart rate and blood pressure were recorded in accordance with the international standards. Participants were categorised as normotensives, pre-hypertensives and hypertensives according to JNC 8 guidelines. Group comparisons were made using the independent t-test and one-way ANOVA for continuous variables, while the Chi-square or Fisher's exact test was used for categorical data. Pearson's correlation coefficient was applied to examine relationships between anthropometric indices and physiological parameters. A p-value of <0.05 was considered statistically significant.

Results:

Among 130 participants, 12 were normotensive, 69 prehypertensive, and 63 hypertensives. Mean RPP rose progressively across BP groups (8453 ± 1514 vs 9951 ± 1292 vs 11773 ± 1736; p < 0.001), while PRQ remained similar (4.27–4.48; p = 0.41). In regression analysis adjusting for age, sex, and BMI, hypertensive status was independently associated with higher RPP (β = 10 891; 95%

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

CI 2445 – 19 337; p = 0.012). BMI showed a positive but nonsignificant trend with RPP (β = 186; p = 0.13). No significant predictors of PRQ were found.

Conclusion:

RPP, but not PRQ, demonstrates potential as a sensitive hemodynamic marker for cardiovascular risk stratification in hypertensive populations, exhibiting significant discriminatory capacity across blood pressure categories.

Background:

Cardiovascular disease (CVD) remains a leading cause of mortality and morbidity worldwide, with hypertension being the major modifiable risk factor. Individuals with hypertension are more prone for developing ischemic heart disease and arrythmias with studies showing a three-fold increased risk of developing cardiovascular disease in persons with blood pressure (BP) >130/80 mmHg when compared to those with BP < 120/80 mmHg (1). By maintaining a healthy diet, regular physical activity and healthy body composition, the risk of acquiring CVD and other non-communicable diseases can be minimised. And, it is a well-known fact that unhealthy lifestyle leads to accumulation of visceral fat and accelerates the process of atherosclerosis, which puts the individual at risk of developing CVD (2). Hypertension and obesity are closely interrelated conditions that independently and synergistically contribute to the pathogenesis of cardiovascular disease. Hence, maintaining appropriate body composition is fundamental to health preservation, with anthropometric parameters offering a practical, non-invasive means of assessing morphological characteristics of an individual.

Anthropometric indices encompass a wide variety of measurements like body mass index, waist circumference, skin fold thickness and many others which helps the clinicians to assess the nutritional status and the risk of obesity related diseases. Body mass index (BMI) is a widely used measure of general adiposity. In a comparative study conducted among Nigerian population, eight anthropometric indicators of obesity were evaluated for their predictive value in identifying prehypertension and hypertension. The findings revealed that Body Mass Index (BMI), Waist Circumference (WC), Waist-to-Hip Ratio (WHtR), and Ponderal Index (PI) served as significant predictors of both prehypertension and hypertension(3). Furthermore, a retrospective analysis of data from 45,853 adults in the United States, derived from the NHANES database, concluded that Body Mass Index (BMI) alone is insufficient for predicting hypertension risk. In contrast, alternative anthropometric measures such as the A Body Shape Index (ABSI) and Conicity Index (CI) demonstrated greater discriminatory ability in identifying individuals at risk of hypertension (4). Waist circumference, a marker of abdominal or central adiposity has been unvaryingly associated with cardiovascular risk. In a six-year follow-up study involving patients with essential hypertension, WC was identified as an independent prognostic marker for coronary artery disease, outperforming BMI and WtHR, emphasizing the prognostic significance of central adiposity over general adiposity measures in hypertensive populations(5).

Rate pressure product (RPP) calculated as the product of heart rate and systolic blood pressure serves as a non-invasive surrogate marker of cardiac workload and myocardial oxygen demand, providing insights into the ischemic strain under resting and stress conditions. Clinically, RPP plays a considerable role in evaluating exercise tolerance, stratifying cardiovascular risk and monitoring treatment interventions. Many studies report elevated RPP among pre -hypertensives and hypertensives relative to normotensives, reflecting a heightened workload on cardiac muscles due to persistent hemodynamic stress. Further, the increase in RPP is often associated with an increased HOMA-IR and tumour necrosis factor alpha, suggesting the underlying metabolic perturbations exacerbating the cardiac oxygen demands and accelerating the onset of overt cardiovascular disease (6). The correlation between anthropometric indices and RPP studied among healthy young adults, revealed a positive correlation between RPP and various measures including BMI, WC and WtHR. This finding reveals the increased workload imposed on myocardium by central adiposity even in apparently healthy individuals (7).

The pulse respiratory quotient (PRQ), obtained as the ratio of heart rate to respiratory rate, reflects the complexity of cardiorespiratory interactions (CRI). These interactions involve the multifaceted interaction between autonomic nervous system, cardiorespiratory centres in brain stem, heart & lungs in thoracic cavity and vascular system (8). Based on a study by Scholkmann et al, PRQ had been found to have two characteristic features, (i) resting state PRQ has a value centered around 4 and (ii) PRQ follows a lognormal distribution. A PRQ value of approximately 4 is known as "PRQ normalization," reflecting the ideal state of cardiovascular function, autonomic nervous system balance, and overall healthy human physiology (9). In hypertensive patients, systolic blood pressure fluctuates more strongly with respiration, though their breathing pattern is similar to that of normotensives. These results emphasize that breathing plays an important role in blood pressure variability and indicate that the extent of respiratory-driven systolic pressure changes may help predict future cardiovascular events in individuals with hypertension (10).

Although these studies do not explicitly compare PRQ values between normotensives and hypertensives, they strongly indicate that hypertension is associated with variations in cardiorespiratory coupling and autonomic dysregulation which would be reflected by PRQ. These findings indicate that PRQ may serve as a potential marker for distinguishing different cardiovascular health states; however, dedicated comparative studies are warranted to substantiate this role.

Previous studies have linked anthropometric indices with blood pressure and rate pressure product and have independently highlighted pulse respiratory quotient as a promising yet relatively unexplored marker of cardiorespiratory–autonomic regulation. However, there is limited evidence examining the interrelationships among these parameters within the same population, particularly in comparative groups of normotensive and hypertensive individuals. The present study addresses this gap by evaluating how body size and fat distribution are simultaneously associated with myocardial workload (RPP) and cardiorespiratory coupling (PRQ) across different blood pressure categories, with the potential to identify simple anthropometric–physiological markers that enhance cardiovascular risk stratification in routine clinical practice.

Methodology:

This observational cross-sectional study was conducted in a tertiary care hospital at Chennai, after obtaining approval from the Institutional Ethics Committee. Adults aged 30 years and above, including newly diagnosed hypertensive individuals and known hypertensives on treatment, were included, while pregnant women and individuals below 30 years of age were excluded. The sample size was calculated using a standard formula for proportions assuming a 95% confidence interval, 10% precision and an expected proportion of 50% due to variation in prevalence data. The minimum required sample size was calculated as 100. However, a total of 130 participants were recruited to improve statistical power, enhance precision, and allow subgroup analysis. After obtaining written informed consent, data were collected using a structured questionnaire covering demographic details, lifestyle factors, medical history, treatment history, and physical activity levels. All the anthropometric measurements were recorded using standardized techniques and calibrated equipment.

Height was measured to the nearest 0.1 cm using a stadiometer, with participants standing barefoot, erect, and with heels, buttocks, shoulders, and occiput touching the vertical surface. Weight was measured to the nearest 0.1 kg using an a digital weighing scale, with participants barefoot and wearing light clothing and body mass index was calculated using the Quetelet index. Waist Circumference (WC) was measured at the midpoint between the lowest palpable rib and the iliac crest at the end of normal expiration. Hip Circumference (HC) was measured at the level of the greater trochanters around the widest portion of the buttocks. Neck Circumference (NC) was measured at the midpoint between the mid-cervical spine and the mid-anterior neck, just below the laryngeal prominence.

Blood pressure (BP) was measured using a validated automated digital sphygmomanometer (Omron HEM-7156T). Participants were instructed to rest for at least 15 minutes prior to measurement, with bladder emptied. They were advised to abstain from caffeine, alcohol, and smoking for at least 30 minutes before BP recording. BP was measured in the sitting position in the left arm, with the arm supported at heart level and appropriate cuff size used. Three readings were taken at intervals of three

Journal of Chemical Health Risks

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JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

minutes, and the average of three readings was considered for analysis.

Pulse Rate (PR) was measured by palpation of the radial artery using the pads of the index, middle, and ring fingers for one full minute. Respiratory Rate (RR) was recorded by observing the thoracoabdominal movements for one minute ensuring that the participant was unaware of the measurement.

Blood pressure was measured using a validated automated digital sphygmomanometer (Omron HEM-7156T). Participants were instructed to rest for at least 15 minutes prior to measurement, and bladder emptied. They were advised to abstain from caffeine, alcohol, and smoking for at least 30 minutes before BP recording. BP was measured in the sitting position in the left arm, with the arm supported at heart level and appropriate cuff size used. Three readings were taken at intervals of three minutes, and the average of the three readings was considered for analysis.

Rate pressure product (RPP) was calculated as the product of heart rate and systolic blood pressure (SBP). Pulse respiratory Quotient (PRQ) was computed as the ratio of pulse rate to respiratory rate. Participants were categorized according to JNC 8 guidelines for hypertension and South Asian BMI cut-off values were used for classifying the participants as overweight and obese. Data were entered in Microsoft Excel and analysis done using SPSS software.

Results:

A total of 130 participants were included in the study and categorized based on blood pressure status into normotensive (n = 10), pre-hypertensive (n = 75), and hypertensive (n = 45) groups. Anthropometric indices, hemodynamic parameters, Rate Pressure Product (RPP), and Pulse Respiration Quotient (PRQ) were analyzed across these groups.

The mean values of anthropometric and functional parameters employed in the study are given in Table 1: Hypertensives exhibited the highest mean RPP, reflecting increased myocardial workload and anthropometric indices (BMI, WC, HC & WtHR) were higher in prehypertensive and hypertensive groups than normotensives. While, the mean PRQ values were similar in prehypertensive and hypertensives groups, with no appreciable variation between them.

TABLE 1: Descriptive statistics across BP categories

VARIABLE	NORMOTENSIVES	PREHYPERTENSIVES	HYPERTENSIVES
Height (cm)	158.40±7.07	156.71±9.35	158.29±6.83
Weight (kg)	63.77±7.70	66.51±8.04	68.73±8.72
Body mass index (kg/m^2)	26.10±2.27	27.44±3.51	26.95±3.74
Waist circumference (cm)	66.10±5.34	70.91±8.90	77.29±9.02
Hip circumference (cm)	82.95±6.47	87.93±8.96	93.25±9.51
Waist to height ratio	0.42±0.03	0.45±0.06	0.49±0.05
Rate pressure product	8257±1502.48	10813.87±1431.22	12406.04±1613.11
Pulse respiratory quotient	4.42±0.62	4.65±0.66	4.65±0.87
Mean arterial BP (mmHg)	82.10±8.96	99.84±6.50	114.36±10.55

One-way analysis of variance (ANOVA) revealed a highly significant difference in Rate Pressure Product across blood pressure categories ($F = 36.16$, $p < 0.001$), as shown in Table 2. In contrast, Pulse Respiration

Journal of Chemical Health Risks
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JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

Quotient did not differ significantly among normotensive, pre-hypertensive, and hypertensive groups (F = 0.84, p = 0.435).

TABLE 2: Comparison of RPP and PRQ across BP categories.

Variable	F value	p value
RPP	36.16	< 0.001*
PRQ	0.84	0.435

The distribution of RPP across blood pressure categories is illustrated in Figure 1, which demonstrates a progressive increase in RPP from normotensives to hypertensives. The upward shift of the median values across blood pressure categories confirms a graded rise in myocardial workload with increasing blood pressure status. Statistical analysis revealed that the intergroup difference in RPP was highly significant (one-way ANOVA, p < 0.001).

Figure 1. Box plot showing the distribution of rate pressure product (RPP) across normotensive, pre-hypertensive, and hypertensive participants.

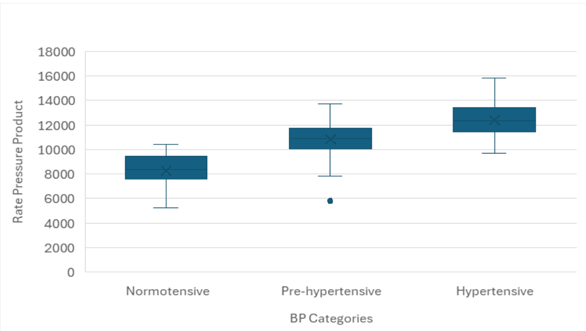
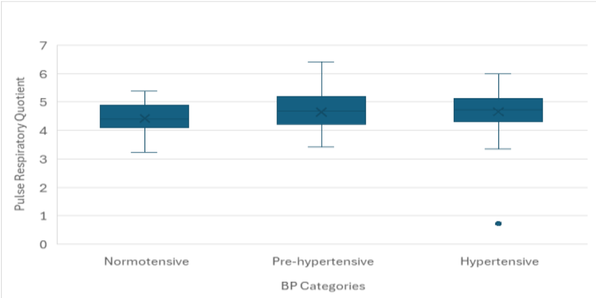


Figure 2 depicts the distribution of pulse respiratory quotient (PRQ) across normotensive, prehypertensive and hypertensive participants using a box plot. Normotensive subjects demonstrated a slightly lower median PRQ, while pre-hypertensive and hypertensive groups showed marginally higher median values. However, the spread of PRQ values was similar across groups, with no consistent pattern of change across BP categories. An isolated lower outlier was noted in the hypertensive group, indicating individual variability. Statistical analysis confirmed that PRQ did not differ significantly among the three blood pressure categories (one-way ANOVA, p > 0.05).

Figure 2. Box plot showing the distribution of pulse respiratory quotient (PRQ) across normotensive, pre-hypertensive, and hypertensive participants.



Pearson's correlation analysis was performed to assess the relationship between anthropometric indices and RPP and PRQ (Table 3). No statistically significant correlations were observed between BMI, waist circumference and waist–hip ratio with either RPP or PRQ (p > 0.05 for all).

TABLE 3: Pearson Correlation Between Anthropometric Indices (BMI and WtHR) and Myocardial Workload Parameters (RPP and PRQ)

VARIABLES	r VALUE (Pearson)	p VALUE
BMI vs RPP	0.06	0.54
BMI vs PRQ	0.05	0.58
WtHR vs RPP	0.09	0.33
WtHR vs PRQ	< 0.001	0.99

Scatter-plot analyses (Figure 3 & 4) showed no obvious linear association between either body mass index or waist-to-hip ratio and cardiac stress markers (RPP & PRQ). The values of both RPP and PRQ were largely dispersed and overlapping for the whole range of General (BMI) and Central Adiposity (WtHR), indicating the absence of any trend of myocardial work or PRQ with the increase in BMI or waist- to- hip ratio.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

FIGURE 3: Relationship between waist to height ratio (WtHR) and myocardial workload indices (RPP & PRQ).

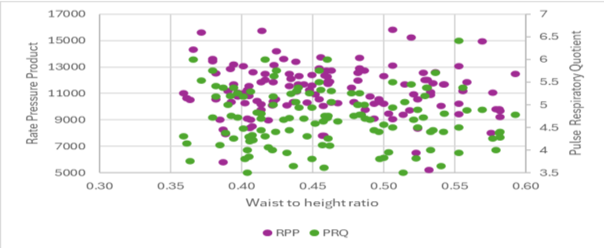
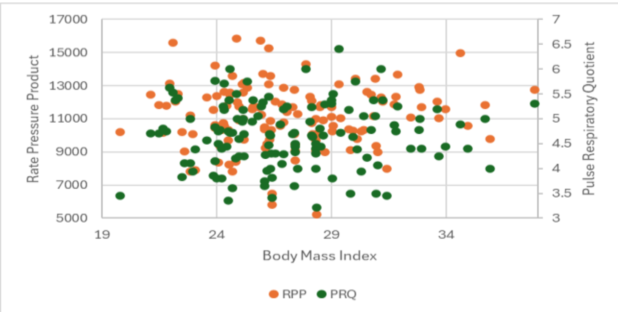


FIGURE 4: Relationship between body mass index (BMI) and myocardial workload indices (RPP & PRQ).



Multiple regression analyses were performed to evaluate the independent association of anthropometric variables with rate pressure product (RPP) and pulse rate quotient (PRQ). Height, weight, body mass index (BMI), waist circumference, and waist-to-height ratio were entered simultaneously into the models.

Multiple regression analyses (Tables 4 & 5) were conducted to evaluate the association between anthropometric variables (height, weight, BMI and WtHR) as predictors and dependent variables being RPP and PRQ. For RPP, the overall model was not statistically significant ($F = 1.338$, $p = 0.245$), explaining only 6.1% of the variance ($R^2 = 0.061$). BMI emerged as a significant predictor ($\beta = 1196.40$, $p = 0.020$) of RPP, indicating a modest influence on myocardial workload. In contrast, height and weight showed weaker effects ($p > 0.05$). For PRQ, none of the anthropometric variables emerged as statistically significant predictors ($F = 1.076$, $p = 0.381$), with the model explaining only 5% of variance.

TABLE 4: Multiple linear regression analysis showing anthropometric predictors of rate pressure product (RPP)

Independent variables	Multiple regression					95.0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
(Constant)	-45326.001	32570.401		-1.392	.167	-109797.114	19145.111
Height	36480.466	20941.356	1.638	1.742	.084	-4971.665	77932.597
Weight	-461.118	207.380	-2.054	-2.224	.028	-871.614	-50.623
BMI	1196.403	509.508	2.249	2.348	.020	187.863	2204.944
WC	147.959	325.525	.743	.455	.650	-496.399	792.316
HC	-35.945	34.207	-.182	-1.051	.295	-103.654	31.765
WtHR	-221.030	513.268	-.710	-.431	.667	-1237.013	794.953

TABLE 5: Multiple linear regression analysis showing anthropometric predictors of pulse respiratory quotient (PRQ)

Independent variables	Multiple regression					95.0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound

Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(1), 2552-2561 | ISSN:2251-6727

	(Constant)	8.305	12.832		.647	.519	-17.095	33.705
	Height	-2.128	8.250	-.244	-.258	.797	-18.459	14.203
	Weight	-.101	.082	-1.153	-1.241	.217	-.263	.060
	BMI	.267	.201	1.284	1.332	.185	-.130	.665
	WC	.243	.128	3.120	1.898	.060	-.010	.497
	HC	-.015	.013	-.191	-1.095	.275	-.041	.012
	WtHR	-.373	.202	-3.055	-1.843	.068	-.773	.028
a. Dependent Variable: PRQ								

Discussion:

The present study examined the association of anthropometric indices with myocardial workload parameters—Rate Pressure Product (RPP) and Pulse Respiratory Quotient (PRQ)—across normotensive, pre-hypertensive, and hypertensive individuals. The major findings signify a progressive and statistically significant increase in RPP with worsening blood pressure status, whereas PRQ remained relatively stable across groups.

RPP, a well-known surrogate marker of myocardial oxygen consumption and cardiac workload, showed a gradual rise from normotensive to hypertensive participants. This finding is physiologically plausible, as RPP reflects the product of systolic blood pressure and heart rate, both of which tend to increase with enhanced sympathetic activity and vascular resistance in hypertension. Meanwhile, another study revealed that RPP can be considered as an index of coronary perfusion and used as a non-invasive quantification measure of myocardial oxygen demand playing a major role in cardiovascular research. This study also emphasizes the necessity of implementing obesity prevention and management strategies in adolescence owing to their higher predisposition to premature coronary artery disease (11).

The significantly higher RPP observed even in the pre-hypertensive group highlights the subclinical cardiovascular burden present before the overt establishment of hypertension. This observation aligns with earlier reports suggesting an elevated RPP among pre-hypertensives with increased BMI (12). Thus, RPP may serve as a sensitive functional marker to identify individuals at increased cardiovascular risk even before pharmacological intervention is warranted. In addition to autonomic imbalance, endothelial dysfunction & increased arterial stiffness also contribute to increased RPP (13). These findings suggest that prehypertension represents a state of subclinical cardiovascular stress rather than a benign transitional state.

In contrast to RPP, PRQ did not demonstrate significant variation across blood pressure categories. PRQ, derived from the ratio of pulse rate to respiratory rate, is considered a crude indicator of cardiorespiratory coupling and autonomic balance. The relative stability of PRQ across groups suggests preserved respiratory-cardiac synchronization despite rising blood pressure levels. There is a dearth of study relating PRQ with blood pressure variability. In a study by Pitzalis et al, it was concluded that the influence of respiratory rate on the variations associated with heart rate and blood pressure in a frequency specific manner and is not mediated by sympathetic system activity (14).

The lack of significant change in PRQ may also be explained by the resting state measurements employed in this study. Autonomic dysregulation in hypertension is often more evident during stress or exercise testing rather than at rest. Therefore, PRQ may have limited sensitivity as a resting marker for hypertensive cardiovascular burden when compared to RPP.

Anthropometric indices such as BMI, waist circumference, hip circumference, and waist-to-height ratio were higher in pre-hypertensive and hypertensive participants, consistent with the established link between adiposity and elevated blood pressure. Our findings were consistent with those reported in another study by Landi et al, which observed a significant increase in SBP and

DBP across different BMI categories (15). Obesity contributes to elevated blood pressure through increased sympathetic activity, sodium retention, and insulin resistance. In addition, adipose-derived inflammatory cytokines and adipokines promote vascular and endothelial dysfunction, further increasing the risk of hypertension (16).

Despite these mechanistic links, Pearson's correlation analysis did not demonstrate significant linear associations between anthropometric indices and RPP or PRQ. This finding suggests that the relationship between adiposity and myocardial workload may not be straightforward or purely linear, especially in heterogeneous populations. It is also possible that confounding variables such as physical activity levels, dietary habits, and genetic predisposition may modulate these associations and were not described in the present analysis.

In the multivariable analysis, anthropometric variables explained approximately 6% of the variance in RPP, with body mass index (BMI) emerging as a significant positive predictor. This suggests that increasing adiposity contributes modestly to elevated resting myocardial workload, consistent with earlier reports linking BMI with increased cardiac oxygen demand (17). Other anthropometric variables apart from BMI, including waist circumference, hip circumference, and waist-to-height ratio, were not independently associated with RPP. Waist circumference is limited in its ability to distinguish between visceral adiposity and abdominal subcutaneous adipose tissue, limiting its utility in cardiometabolic risk stratification (18). While binary analyses in earlier literature identified waist-hip ratio and waist-height ratio as strong predictors of hypertensive status (19) , the present study suggests that their independent contribution may be weakened when multiple anthropometric measures are considered simultaneously.

For PRQ, the model explained approximately 5% of the variance, with no anthropometric variable demonstrating a significant association. This indicates that cardiorespiratory coupling is largely independent of static body size and is predominantly regulated by autonomic and respiratory mechanisms. These findings were consistent with that reported by Dick et al, stating that cardiorespiratory control system function as a weakly coupled oscillator, allowing heart rate and respiratory rhythm to remain synchronised while preserving the variability within physiological limits (20).

The findings of the present study emphasize the clinical utility of RPP as a simple, non-invasive marker for early cardiovascular stress in individuals with elevated blood pressure. The observation that RPP increases significantly even in pre-hypertension reinforces the need for early lifestyle interventions targeting weight management and blood pressure control. Our study findings also highlight that although anthropometric indicators are strongly associated with hypertension prevalence, their ability to explain resting myocardial workload and cardiorespiratory coupling remains modest. This reinforces the need to integrate functional, metabolic, and autonomic markers to better characterise cardiovascular risk beyond static body measurements.

Limitations and Future Directions:

The cross-sectional design of the study limits the causal interpretation between anthropometry and myocardial workload. The relatively smaller normotensive group may have reduced the power to detect subtle differences. Additionally, measurements were obtained at rest, and dynamic autonomic responses were not evaluated. Future longitudinal studies incorporating exercise testing, heart rate variability, and metabolic parameters may provide deeper insights into the cardio-metabolic interactions underlying hypertension.

Conclusion:

In summary, the study demonstrates a significant increase in myocardial workload, as measured by RPP, with progressive increase in blood pressure status. Body mass index emerged as an independent predictor of RPP, implying that excess adiposity further increases the cardiovascular load in addition to increased blood pressure. PRQ, remained relatively unchanged across blood pressure categories, suggesting limited sensitivity as a resting cardiovascular stress marker. These findings highlight the importance of monitoring myocardial workload in hypertensive populations and reinforce that maintaining an ideal body weight is crucial for a better cardiovascular health.

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