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Association of Heart Rate Variability and Baroreflex Sensitivity with Blood Pressure Control in Essential Hypertension: A Hospital-Based Cross-Sectional Study

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ABSTRACT

Background: The dysfunction of the autonomic nervous system is a major pathophysiologic agent in essential hypertension and potentially a factor in insufficient blood pressure management despite pharmacological therapy. Non-invasive indicators of autonomic cardiovascular regulation include heart rate variability (HRV) and baroreflex sensitivity (BRS); nevertheless, their role in blood pressure management in non-acute clinical life has not been studied well enough.

Objectives: To determine the relationship between heart rate variability and baroreflex sensitivity with blood pressure regulation in essential hypertension patients.

Methods: This was a cross-sectional study that took place between May 2024 and May 2025 and involved 100 adults with essential hypertension. Standardized procedures were employed in measuring blood pressure, and the respondents were divided into two groups, namely controlled and uncontrolled hypertension. HRV measurements were made in both time and frequency domains through short-term electrocardiograph recordings, whereas baroreflex sensitivity was measured under a non-invasive spontaneous sequence approach. These were done by using comparative and correlation analyses in order to explore the relationship between the autonomic parameters and blood pressure levels.

Results: Of the 100 participants, 46% had controlled hypertension and 54% had uncontrolled hypertension. Uncontrolled hypertension patients recorded much lower HRV indices, such as SDNN and RMSSD, as well as high-frequency power, and a much higher LF/HF ratio ($p < 0.001$). In the state of uncontrolled, baroreflex sensitivity was significantly lower ($p < 0.001$). There were strong negative relationships between systolic and diastolic blood pressure variables and HRV parameters and baroreflex sensitivity. Multivariate regression analysis has revealed that reduced baroreflex sensitivity and lower SDNN are the independent predictors of poor blood pressure control.

Conclusion: Impaired autonomic regulation, reflected by reduced heart rate variability and baroreflex sensitivity, is strongly associated with uncontrolled essential hypertension. Assessment of autonomic function may enhance risk stratification and support more individualized management of hypertensive patients.

Keywords: Essential hypertension, heart rate variability, baroreflex sensitivity, autonomic dysfunction, blood pressure control

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INTRODUCTION

Essential hypertension is a common chronic cardiovascular disease and is considered one of the most important sources of modifiable risk factors of morbidity and mortality in the world [1]. It has a significant contribution to the onset of coronary artery disease, stroke, heart failure, chronic kidney disease, and premature death. Although there are improved diagnostic approaches and numerous antihypertensive drugs that are effective, improved blood pressure control is obtained in the presence of only a percentage of patients.

This constant difference between access to treatment and effective control indicates the participation of complicated control mechanisms other than traditional hemodynamic ones [2].

The pathway of blood pressure regulation is dynamic and is regulated by the concerted efforts of the neural, hormonal, renal, and vascular systems [3]. The autonomic nervous system is one of the major systems that contribute to the stability of the short and long-term cardiovascular conditions. The existence of imbalance, where the sympathetic system is more activated, and the parasympathetic is less modulated, has been persistently involved in the onset, support, and progression of essential hypertension [4]. This autonomic maladaptation not only contributes to the maintenance of elevated blood pressure but also increases the degree of cardiovascular risk and variability of blood pressure [5].

The heart rate variability is a quantitative, non-invasive measure of autonomic cardiac variation. It shows beat-to-beat variation of heart rate resulting from the interaction between sympathetic and parasympathetic activity on the sinoatrial node [6]. The decreased variability of heart rate suggests that there is less autonomic flexibility and less control by the vagus, and this has been linked to the severity of hypertension, damage to target organs, and poor cardiovascular outcomes. Notably, heart rate variability gives a clue to the autonomic functioning that cannot be recorded by the standard blood pressure measurements [7].

Another important element of cardiovascular autonomic control is the baroreflex sensitivity. Arterial baroreflex is a fast-buffering mechanism, which maintains the blood pressure by varying the heart rate and vascular tone in relation to the alterations in arterial pressure [8]. Baroreflex activity in essential hypertension may be blunted so that the buffering capacity becomes impaired and there is increased vulnerability to fluctuations in blood pressure. It has been linked with impaired baroreflex sensitivity, sustained hypertension, elevated sympathetic drive, and cardiovascular risk [9].

Despite the well-knownness of autonomic dysfunction in essential hypertension, the interaction between heart rate variability and baroreflex sensitivity, and the real status of blood pressure control in hypertensive patients under medical care has been inadequately studied, especially in normal hospital-based groups [10]. Most clinical examinations pay much attention to the values of blood pressure, and to some extent, neglect the existence of underlying autonomic dysfunction, which can lead to ineffective control and resistance to therapy [11].

The knowledge of the relationship between autonomic indices with blood pressure control can be of great importance to understand the pathophysiology of essential hypertension and ensure the identification of patients who are at greater risk of persistent hypertension and cardiovascular complications. The knowledge might also support the rationale that would justify the introduction of autonomic function assessment into clinical practice and positively contribute to the development of particular methods, which might facilitate the restoration of the autonomic balance [12].

Therefore, the aims and objectives of the current study were to evaluate the correlation between heart rate variability and the baroreflex sensitivity with blood pressure regulation in patients with essential hypertension under a hospital-outpatient setting [13].

MATERIALS AND METHODS

The study is a cross-sectional, conducted from May 2024 to May 2025 in the departments of medicine, Ghurki Trust Teaching Hospital, Lahore, and Quaid-e-Azam Medical College (QAMC), Bahawalpur, Pakistan. The aim of the study was to establish the correlation between the operations of the autonomic nervous system evaluated by the heart rate variability (HRV) and baroreflex sensitivity (BRS) and blood pressure regulation among patients with essential hypertension.

The enrolment of 100 adult patients with essential hypertension was conducted by using non-probability consecutive sampling. The qualified participants were found to be aged between 30 to 65 years old with a history of essential hypertension for at least one year.

Only those patients who were on stable antihypertensive therapy for at least three months before enrolment were included. Patients who had secondary causes of hypertension, diabetes mellitus, ischemic heart disease, heart failure, cardiac arrhythmias, chronic kidney disease, cerebrovascular disease, autonomic neuropathy, acute infections, or inflammatory conditions were not included. Patients who were on drugs that are known to play a major role in the autonomic functioning, like the beta-blockers or antiarrhythmic drugs, were also not included in the study.

The calibrated mercury sphygmomanometer was used to measure blood pressure according to the standardized international protocols. One recorded measurement was taken when the participant was at rest in the sitting position, taking at least five minutes to rest. Three consecutive readings were recorded every five minutes, and the mean of all the readings was analyzed. Participants were considered to have controlled hypertension with systolic blood pressure measures of below 140 mmHg and diastolic measures of less than 90 mmHg, and those with systolic measures of 140 mmHg and above and/or diastolic measures of 90 mmHg and above, because of the values of these parameters relative to the office blood pressure.

The heart rate variability was measured using short-term electrocardiograms. Subjects were advised to avoid caffeine, smoking, and vigorous physical activity for at least twelve hours before testing. Recordings were conducted in a well-ventilated, cool room, with participants lying in a supine position after resting for ten minutes. A five-minute ECG was continuously recorded, and heart rate variability was analyzed using validated software. Time-domain

measures, such as the standard deviation of normal-to-normal intervals and the root mean square of successive differences, were used to assess overall autonomic variance and parasympathetic activity. Frequency-domain analysis was performed to identify power in low and high-frequency components, and the ratio of low to high frequencies served as a measure of sympathovagal balance.

The sensitivity of the baroreflex was determined by a non-invasive spontaneous sequence. The sequential changes in systolic blood pressure with a corresponding change in R-R interval were identified by analysing continuous ECG and blood pressure records. The baroreflex sensitivity was determined as the slope of the linear regression of the change in the systolic blood pressure and changes in the R-R interval expressed in milliseconds per millimeter of mercury.

The Institutional Ethics Review Committees of Quaid-e-Azam Medical College, Bahawalpur, and Ghurki Trust Teaching Hospital, Lahore, Pakistan (Approval No. QAMC/ERC/2024/104) were the ethics review boards that provided the ethical approval. Informed consent was obtained in writing, and all the participants were informed about the objectives and procedures of the study in detail. Confidentiality of the participants was upheld during the study, and all data were anonymized before analysis.

SPSS version 26.0 was used to conduct the statistical analysis. The continuous variables were presented in the form of the mean and standard deviation, and the categorical variables were shown in the form of frequencies and percentages. Independent sample t-tests were used to perform comparisons between the groups of controlled and uncontrolled hypertension. The correlation analysis was performed by Pearson correlation analysis to assess the relationship between the values of blood pressure, heart rate variability indices, and baroreflex sensitivity. The multivariate regression analysis was done in order to establish independent predictors of poor blood pressure control after controlling for the predictors of age, gender, body mass index, and duration of hypertension. A p-value of below 0.05 was considered statistically significant.

RESULTS

Demographic and Clinical Characteristics: The study involved 100 patients who had essential hypertension. The sample was 58 men (58 percent) and 42 women (42 percent), and the average age of the sample was 52.37 years old. According to the office blood pressure measurements, 46 patients (46) had controlled hypertension, and 54 patients (54) had uncontrolled hypertension.

The control and non-control hypertension groups had no statistically significant difference in terms of age, gender composition, body mass index, and years of hypertension ($p > 0.05$). Systolic and diastolic blood pressure measures were also correspondingly and statistically different ($p < 0.001$) in the uncontrolled group, which is a good indication of proper group classification. Table 1 summarises the baseline demographic and clinical characteristics.

Heart Rate Variability Analysis: The level of heart rate variability was significantly reduced in patients with uncontrolled hypertension as compared to patients with controlled blood pressure. Time-domain analysis revealed that the SDNN and RMSSD values were significantly different between the uncontrolled groups with lower overall autonomic variability and decreased parasympathetic activity ($p < 0.001$ for both).

Frequency-domain analysis also showed much lower high-frequency (HF) power and a much higher LF/HF ratio in the uncontrolled hypertension patient group, which indicates sympathetic dominance and disordered sympathovagal balance. The uncontrolled group had a low-frequency power marginally higher and was statistically significant.

Gender-wise comparison showed that both uncontrolled hypertension patients, males and females, showed an equal shift in the HRV parameters without a statistically significant interaction between gender and HRV indices. Table 2 provides the comparative results of HRV.

Baroreflex Sensitivity: The baroreflex sensitivity was also much lower among the patients whose hypertension was out of control than it was among those whose blood pressure was under control. The standard baroreflex sensitivity in the uncontrolled group was approximately 40 percent less than the standard cardiovascular reflex regulation, which proved to have significant impairment ($p < 0.001$).

The female and male participants experienced similar reductions in baroreflex sensitivity of the uncontrolled group and did not demonstrate a statistically significant gender difference. The results of the baroreflex sensitivity are presented in Table 3.

Table 1: Baseline demographic and clinical characteristics of the study population

Variable	Controlled Hypertension (n = 46)	Uncontrolled Hypertension (n = 54)	p-value
Age (years)	51.8 ± 8.3	52.7 ± 8.9	0.62
Male, n (%)	27 (58.7%)	31 (57.4%)	0.89
Female, n (%)	19 (41.3%)	23 (42.6%)	0.89
Body mass index (kg/m²)	26.4 ± 3.1	26.9 ± 3.4	0.44
Duration of hypertension (years)	6.2 ± 2.4	6.6 ± 2.7	0.48
Systolic BP (mmHg)	128.6 ± 7.9	152.4 ± 11.6	<0.001
Diastolic BP (mmHg)	82.1 ± 5.8	96.3 ± 8.2	<0.001

Table 2: Comparison of heart rate variability parameters between controlled and uncontrolled hypertension

HRV Parameter	Controlled Hypertension (n = 46)	Uncontrolled Hypertension (n = 54)	p-value
SDNN (ms)	42.8 ± 10.6	28.9 ± 9.4	<0.001
RMSSD (ms)	36.2 ± 8.7	22.4 ± 7.9	<0.001
LF power (ms²)	612 ± 148	684 ± 172	0.04
HF power (ms²)	489 ± 132	296 ± 118	<0.001
LF/HF ratio	1.34 ± 0.42	2.36 ± 0.58	<0.001

Table 3: Comparison of baroreflex sensitivity between study groups

Parameter	Controlled Hypertension (n = 46)	Uncontrolled Hypertension (n = 54)	p-value
Baroreflex sensitivity (ms/mmHg)	10.6 ± 3.1	6.3 ± 2.4	<0.001

Correlation Between Blood Pressure and Autonomic Parameters: The correlation analysis showed that there was a significant negative association between the indices of autonomic functions and the level of blood pressure. Systolic and diastolic blood pressure were both in a negative relationship with SDNN, RMSSD, HF power, and baroreflex sensitivity ($p < 0.01$). Conversely, the systolic blood pressure had a significant positive correlation to the LF/HF ratio, implying that with the rise in blood pressure, there was an increasing sympathetic dominance. These associations crossed the gender lines.

Even after controlling for the variables of age, gender, body mass index, and duration of hypertension, low SDNN values and low levels of baroreflex sensitivity were independent predictors of uncontrolled hypertension. This observation highlights the high role of autonomic dysfunction in the poor management of blood pressure, beyond the conventional demographic and clinical variables.

DISCUSSION

The current cross-sectional investigation of the function of the autonomic nervous system in the hospital setting shows that autonomic nervous system dysfunction is strongly linked to poor blood pressure control in essential hypertension patients [13]. The patients who had uncontrolled hypertension had significantly lower heart rate variability and baroreflex sensitivity as compared to patients with controlled blood pressure. The findings explain the importance of autonomic imbalance in the stasis, onset, and severity of essential hypertension [14].

Heart rate variability is a commonly known non-invasive cardiac autonomic regulation marker. In the current study, SDNN and RMSSD changes were significant in the patients who had not obtained hypertension control and showed the absence of general autonomic modulation and reduced parasympathetic actions [15]. The findings agree with the previous studies that have observed a low vagal tone and high sympathetic dominance among individuals with hypertensive conditions. Reduced HRV means that physiological adaptability of the cardiovascular system is lost and may result in long-term elevated blood pressure and increased cardiovascular risk [16].

Frequency-domain analysis also confirmed the existence of an autonomic imbalance in hypertension that was not controlled. The high-frequency power levels and LF/HF ratio in this group are significantly lower, which is a sign of a parasympathetic withdrawal and sympathetic preeminence [17]. Sympathetic hyperactivity has been known to raise heart rate, vascular resistance, as well as sodium retention, which is a cause of hypertension as well as maintenance of hypertension. The uniformity of these results in both males and females indicates that autonomic dysregulation is a primary mechanism in blood pressure regulation regardless of gender [18].

The sensitivity to baroreflexes was also very poor in patients with uncontrolled high blood pressure. The arterial baroreflex is a vital short-term control process that maintains normal blood pressure by adjusting heart rate and vascular tone in relation to the arterial pressure [19]. Damage to this reflex impairs the capacity of the body to maintain changes in blood pressure, resulting in a rise in blood pressure variability and chronic hypertension. The already high percentage change of baroreflex sensitivity (about 40 percent) in uncontrolled hypertensive patients only makes the enormous severity of autonomic dysfunction of uncontrolled hypertensive patients [20].

The correlation analysis also provides a stronger physiological significance of these results. Systolic and diastolic blood pressure exhibited a strong negative relation with the HRV indices and baroreflex sensitivity, which implies that the deterioration of blood pressure control is linked to the progressive autonomic dysfunction. The positive relationship between systolic blood pressure and LF/HF ratio underlines the role of the sympathetic dominance in increasing the level of blood pressure [1-6].

Notably, the multivariate regression analysis indicated that decreased baroreflex sensitivity and lower SDNN remained independent predictors of uncontrolled hypertension despite age, gender, body mass index, and hypertension duration. This implies that autonomic dysfunction is an independent risk factor in the lack of control over blood pressure, regardless of usual clinical variables. Such results could be one of the reasons why antihypertensive therapy is not controlled in some patients despite adherence to it [15,19].

Clinically, the findings in this study highlight how the assessment of autonomic functions could be of benefit in a regular assessment of hypertensive patients [13,17]. Autonomic impairment can be detected and help to stratify the patients who are at a higher risk of inadequate blood pressure management and cardiovascular adverse events. In

addition, the autonomic balance intervention, such as regular exercise, stress, weight, and special pharmacological strategies, might bring certain additional benefits in the sphere of blood pressure [20].

CONCLUSION

This cross-sectional study was conducted that indicated that the heart rate variability and baroreflex sensitivity are less than normal, which suggests that there are strong links between the research findings and blood pressure control in patients with essential hypertension. At the centre of the sustenance of uncontrolled hypertension is dysfunction of the autonomic nervous system, which is characterized by preeminence of the sympathetic and low parasympathetic modulation. Situated at the usual blood pressure rates, autonomic function assessment may bring valuable information to the latter and enable to reveal the patients who are under greater risk of inadequate control. One of the possible ways to improve personalized and effective approaches to essential hypertension management is to incorporate autonomic assessment in clinical practice.

Availability of Data and Materials: Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Authors' Contributions: SMAY conceptualized and designed the study, supervised data collection, and critically reviewed the manuscript for important intellectual content. MB contributed to data collection, patient assessment, and initial drafting of the manuscript. MJM performed statistical analysis, data interpretation, and assisted in results presentation. SMAW contributed to data validation, literature review, manuscript editing, and final proofreading. All authors read and approved the final version of the manuscript.

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