ORIGINAL ARTICLE

NUREXUS

Journal of MedVerse Research & Practice

ISSN: 3107-4278

Heart Rate Variability and Stress Levels among Undergraduate Medical Students

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Submission Date: 03.06.2026	Accepted Date:15.07.2026	Published Date: 31.07.2026
DOI: 10.65188/nurexus.1091		

Abstract

Background: Medical students are frequently exposed to academic, emotional, and psychological stress, which can adversely affect autonomic nervous system function. Heart Rate Variability (HRV) is a reliable, non-invasive indicator of autonomic balance and can be used to objectively assess physiological responses to stress. This study aimed to evaluate the association between heart rate variability and perceived stress among undergraduate medical students.

Materials and Methods: A cross-sectional observational study was conducted among 150 undergraduate medical students in the Department of Physiology, Mediciti Institute of Medical Sciences, Ghanpur. Perceived stress was assessed using the Perceived Stress Scale (PSS-10), and HRV was recorded under standardized resting conditions. Time-domain parameters (SDNN and RMSSD) and the frequency-domain parameter (LF/HF ratio) were analyzed. Statistical analysis was performed using SPSS version 25.0, with $p < 0.05$ considered statistically significant.

Results: The mean age of the participants was 20.8 ± 1.5 years, and 54.0% were females. Moderate stress was observed in 62.0% of students, while 24.0% experienced high stress. SDNN and RMSSD decreased significantly with increasing stress levels, whereas the LF/HF ratio increased significantly ($p < 0.001$). Perceived stress showed a significant negative correlation with SDNN ($r = −0.42$) and RMSSD ($r = −0.39$), and a positive correlation with the LF/HF ratio ($r = 0.36$, $p = 0.002$).

Conclusion: Higher perceived stress was significantly associated with reduced heart rate variability, indicating impaired autonomic function among undergraduate medical students. Early stress identification and targeted interventions may improve autonomic health and psychological well-being.

Keywords

Heart Rate Variability; Stress; Perceived Stress Scale; SDNN; RMSSD; LF/HF Ratio; Undergraduate Medical Students; Autonomic Nervous System.

Introduction

Medical education is widely recognized as one of the most demanding professional training programs, requiring students to cope with intensive academic schedules, frequent examinations, clinical responsibilities, and continuous assessment. These academic commitments are often accompanied by inadequate sleep, limited leisure time, social adjustments, and concerns regarding future career prospects. The cumulative effect of these factors places undergraduate medical students at a greater risk of experiencing psychological stress than many of their age-matched peers. Although a certain level of stress may enhance motivation and learning, persistent or excessive stress can adversely affect emotional well-being, academic performance, interpersonal relationships, and physical health [1,2].

Psychological stress produces measurable physiological changes through activation of the autonomic nervous system and the hypothalamic-pituitary-adrenal axis. During stressful situations, sympathetic nervous system activity increases while parasympathetic activity decreases, enabling the body to respond to immediate demands. However, sustained sympathetic activation without adequate recovery may lead to autonomic imbalance, contributing to fatigue, impaired concentration, anxiety, depression, hypertension, metabolic disturbances, and increased cardiovascular risk [3,4]. Therefore, identifying objective indicators of stress has become an important area of research in student health. Heart rate variability (HRV) is a non-invasive and reliable measure of autonomic nervous system function that reflects the variation in time intervals between consecutive heartbeats. It provides valuable information regarding the balance between sympathetic and parasympathetic activity. Individuals with higher HRV generally demonstrate better autonomic adaptability and greater resilience to physical and psychological stress, whereas lower HRV is indicative of reduced vagal tone, impaired autonomic regulation, and diminished physiological flexibility [3-5]. Previous studies have reported a consistent association between chronic psychological stress and reduced HRV, suggesting that autonomic dysfunction may develop even in otherwise healthy young adults exposed to prolonged stress [5,6].

Medical students constitute an ideal population for evaluating this relationship because they are routinely exposed to multiple academic and psychosocial stressors throughout their training. While perceived stress is commonly assessed using validated self-report questionnaires, HRV offers an objective physiological assessment that complements subjective findings. Examining both parameters together can provide a more comprehensive understanding of stress-related autonomic changes and help identify students who may benefit from early support [6,7]. Assessing the relationship between heart rate variability and perceived stress among undergraduate medical students may contribute to the early detection of stress-related autonomic dysfunction before clinically significant health problems develop. The findings may support the implementation of evidence-based interventions such as stress management programs, mindfulness training, regular physical activity, and psychological counseling to improve students' mental well-being and autonomic health. Such information may also assist educational institutions in developing strategies that promote resilience, improve learning environments, and enhance the overall health and academic success of future healthcare professionals [7,8].

Materials & Methods

Study Design

This cross-sectional observational study was conducted to assess the relationship between perceived stress and heart rate variability (HRV) among undergraduate medical students.

Study Setting and Duration

The study was conducted in the Department of Physiology, Mediciti Institute of Medical Sciences, Ghanpur, during the predefined study period. Institutional Ethics Committee approval was obtained prior to the commencement of the study, and all procedures were carried out in accordance with the ethical principles governing biomedical research involving human participants.

Study Population

The study population consisted of undergraduate medical students enrolled at Mediciti Institute of Medical Sciences. A total of 150 students who fulfilled the eligibility criteria and voluntarily agreed to participate were included after obtaining written informed consent.

Sample Size

A total of 150 undergraduate medical students were included in the study. The sample size was determined based on the number of eligible students available during the study period who met the inclusion criteria and consented to participate.

Inclusion Criteria

Apparently healthy undergraduate medical students aged between 18 and 25 years who were willing to participate in the study and provided written informed consent were included.

Exclusion Criteria

Students with a history of cardiovascular disease, hypertension, diabetes mellitus, psychiatric illness, neurological disorders, chronic systemic diseases, acute illness at the time of data collection, or those receiving medications known to influence autonomic nervous system function, such as beta-blockers, antidepressants, or antiarrhythmic drugs, were excluded from the study.

Data Collection Tool

Eligible participants were recruited after explaining the objectives and procedures of the study and obtaining written informed consent. Demographic information, including age, sex, and year of study, was collected using a structured questionnaire. Perceived stress was assessed using the validated Perceived Stress Scale-10 (PSS-10), which measures the degree to which individuals perceive stressful situations during the preceding month. Heart rate variability was recorded under standardized resting conditions in a quiet, temperature-controlled environment using a validated HRV recording system. Participants were instructed to avoid caffeine, alcohol, smoking, strenuous physical activity, and heavy meals before HRV assessment to minimize factors influencing autonomic function. Time-domain HRV parameters, including the standard deviation of normal-to-normal intervals (SDNN) and the root mean square of successive differences (RMSSD), as well as frequency-domain parameters including low-frequency (LF) power, high-frequency (HF) power, and the LF/HF ratio, were recorded to assess autonomic nervous system activity.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Ethics Committee of Mediciti Institute of Medical Sciences, Ghanpur. Written informed consent was obtained from all participants before enrolment. Participant confidentiality and anonymity were maintained throughout the study by assigning unique identification numbers and ensuring that all collected information was used solely for research purposes.

Statistical Analysis

The collected data were entered into Microsoft Excel for coding and cleaning before being analyzed using IBM Statistical Package for the Social Sciences (SPSS) software version 25.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Pearson's correlation coefficient was used to assess the relationship between perceived stress scores and heart rate variability parameters. Appropriate comparative statistical tests were applied based on the distribution of the data, and a *p*-value of less than 0.05 was considered statistically significant.

Result

Table 1. Baseline Characteristics of the Study Participants (n = 150)

Variable	Value
Age (years), Mean ± SD	
Male, n (%)	69 (46.0)
Female, n (%)	81 (54.0)

The study included 150 undergraduate medical students with a mean age of 20.8 ± 1.5 years. Female participants (54.0%) slightly outnumbered males (46.0%).

Table 2. Distribution of Stress Levels (PSS-10)

Stress Level	Frequency (n)	Percentage (%)
Low Stress	21	14.0
Moderate Stress	93	62.0
High Stress	36	24.0

Most participants (62.0%) experienced moderate stress, while 24.0% reported high stress, indicating that stress is common among undergraduate medical students.

Table 3. Comparison of HRV Parameters According to Stress Levels

HRV Parameter	Low Stress	Moderate Stress	High Stress
SDNN (ms)	58.6 ± 9.4	49.7 ± 8.6	39.8 ± 7.5
RMSSD (ms)	46.2 ± 7.8	38.5 ± 6.9	30.4 ± 5.8
LF/HF Ratio	1.42 ± 0.34	1.89 ± 0.42	2.63 ± 0.58

Increasing stress levels were associated with a significant decrease in SDNN and RMSSD and a significant increase in the LF/HF ratio ($p < 0.001$), indicating reduced parasympathetic activity and increased sympathetic dominance.

Table 4. Correlation Between Perceived Stress and HRV Parameters

Variable	Correlation (r)	p-value
PSS vs SDNN	-0.42	<0.001
PSS vs RMSSD	-0.39	<0.001
PSS vs LF/HF Ratio	0.36	0.002

Perceived stress showed a moderate negative correlation with SDNN and RMSSD, and a positive correlation with the LF/HF ratio, demonstrating that higher stress is associated with impaired autonomic function.

Table 5. Summary of Major Findings

Finding	Result
Mean Age	20.8 ± 1.5 years
Moderate Stress	62.0%
High Stress	24.0%
Significant Reduction in SDNN & RMSSD	Yes ($p < 0.001$)
Significant Increase in LF/HF Ratio	Yes ($p < 0.001$)
Significant Correlation Between Stress and HRV	Yes ($p < 0.05$)

The study demonstrated that higher perceived stress was significantly associated with reduced heart rate variability, suggesting altered autonomic balance among undergraduate medical students. These findings highlight the importance of stress management strategies to improve students' cardiovascular and psychological well-being.

Discussion

Perceived stress is increasingly recognized as a significant determinant of autonomic nervous system function among medical students because of prolonged academic demands, emotional stressors, and competitive learning environments. In the present study, students with higher perceived stress demonstrated significantly lower SDNN and RMSSD values along with a significantly higher LF/HF ratio, indicating reduced parasympathetic activity and increased sympathetic predominance. A significant negative correlation was observed between Perceived Stress Scale (PSS-10) scores and heart rate variability (HRV) parameters ($p < 0.001$), suggesting that increasing psychological stress adversely affects autonomic regulation.

Yoo et al. (2021) demonstrated that HRV is a useful objective marker for assessing stress among medical students and reported that alterations in autonomic balance were associated with increased academic stress during clinical training [1]. Similarly, Miller et al. (2022) observed that students with higher perceived stress scores had significantly reduced HRV parameters, reflecting impaired parasympathetic activity and altered sympathovagal balance [2]. These findings are consistent with the present study, where higher stress

levels were associated with significantly lower SDNN and RMSSD values. LeBlanc et al. (2025) further demonstrated that HRV-derived parameters correlate closely with physiological and psychological measures of stress among healthcare learners and suggested that HRV can serve as a reliable, non-invasive biomarker for objective stress assessment [3]. Likewise, Kim et al. (2022) reported that medical students with elevated stress exhibited significantly reduced HRV indices, indicating autonomic dysfunction secondary to chronic psychological stress [4]. The present study similarly demonstrated a significant inverse relationship between perceived stress scores and HRV parameters, reinforcing the value of HRV in stress evaluation.

Shaffer et al. (2020) emphasized that HRV represents a sensitive physiological indicator of autonomic nervous system regulation and highlighted the importance of standardized HRV assessment in stress research [9]. McEwen (2020) explained that chronic psychological stress activates the hypothalamic-pituitary-adrenal axis and sympathetic nervous system, leading to sustained autonomic imbalance and adverse cardiovascular consequences [10]. These mechanisms support the present findings, where increased perceived stress was associated with reduced parasympathetic modulation and elevated sympathetic activity. Taelman et al. (2021) demonstrated that mental stress significantly reduces HRV by increasing sympathetic activation and suppressing vagal activity, thereby altering autonomic balance [11]. Similarly, Kim et al. (2023) reported that university students with higher psychological stress had significantly reduced HRV indices, confirming the relationship between stress and autonomic dysfunction [12]. These observations closely correspond with the present study, which identified lower SDNN and RMSSD values and higher LF/HF ratios among students experiencing greater perceived stress.

Amin et al. (2025) reported that HRV effectively identifies stress among undergraduate students, with higher stress levels associated with reduced HRV and increased LF/HF ratio, indicating sympathetic predominance [14]. Malik and Camm (2021) highlighted the clinical utility of HRV as a reliable measure of autonomic nervous system function and emphasized its application in monitoring stress-related physiological changes [15]. Raj (2022) further stated that reduced HRV is associated with impaired autonomic regulation and may predispose individuals to future cardiovascular morbidity if persistent stress remains unaddressed [16]. Overall, the findings of the present study are consistent with previous literature demonstrating that increased perceived stress is associated with significant autonomic imbalance characterized by reduced parasympathetic activity and increased sympathetic dominance. These findings support the incorporation of stress management strategies, psychological counselling, mindfulness practices, relaxation techniques, and lifestyle modifications within medical education to improve students' psychological well-being and maintain healthy autonomic nervous system function.

Strengths

This study employed a validated Perceived Stress Scale (PSS-10) together with standardized heart rate variability assessment under controlled conditions, providing an objective evaluation of autonomic nervous system function in relation to perceived stress among medical students. The use of both time-domain and frequency-domain HRV parameters enhanced the comprehensiveness of autonomic assessment.

Limitations

The cross-sectional design precludes the establishment of a causal relationship between perceived stress and heart rate variability. In addition, the study was conducted in a single medical institution with a relatively limited sample size, which may restrict the generalizability of the findings. Factors such as sleep quality, dietary habits, and recent academic workload, which could influence stress levels and HRV, were not comprehensively evaluated.

Conclusion

Higher perceived stress was significantly associated with reduced heart rate variability, reflected by lower

SDNN and RMSSD and a higher LF/HF ratio. These findings suggest that stress adversely affects autonomic function among undergraduate medical students, emphasizing the need for early stress management strategies.

Declaration

Conflict of Interest: The authors declare that they have no competing interests or conflicts of interest related to this work.

Funding: Nil

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