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An Observational Study of Heart Rate Variability and Perceived Stress among Undergraduate Medical Students.

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Abstract

Background: Medical students are exposed to sustained academic and psychosocial stress, which can influence autonomic regulation. Heart rate variability [HRV] provides a noninvasive physiological measure of autonomic balance, while the Perceived Stress Scale [PSS] reflects subjective stress appraisal. ***Objectives:*** To assess perceived stress and HRV among undergraduate medical students and to evaluate the association between stress levels and HRV parameters. ***Methods:*** This observational cross-sectional study was conducted among 100 undergraduate medical students at Prathima Institute of Medical Sciences, Karimnagar, Telangana, from June 2025 to November 2025. Perceived stress was assessed using the PSS-10. Short-term resting HRV was analyzed using time-domain and frequency-domain parameters. HRV indices were compared across stress categories, and correlations between PSS score and HRV measures were examined. ***Results:*** The mean age of participants was 20.6 ± 1.4 years, and 56.0% were females. The mean PSS score was 20.8 ± 6.1. Low, moderate, and high perceived stress were observed in 18.0%, 62.0%, and 20.0% of students, respectively. Higher stress was associated with lower SDNN, RMSSD, pNN50, and HF power, along with higher resting heart rate and LF/HF ratio. PSS score showed significant negative correlations with SDNN, RMSSD, pNN50, and HF power, and positive correlations with resting heart rate and LF/HF ratio. ***Conclusion:*** Moderate to high perceived stress was common among undergraduate medical students and was associated with reduced HRV, suggesting autonomic imbalance with greater psychological stress. Combined psychological and physiological assessment can help identify students who may benefit from early supportive interventions.

Keywords: heart rate variability; perceived stress; medical students; autonomic function; undergraduate students; PSS-10.

INTRODUCTION

Medical education is widely recognized as intellectually demanding, emotionally taxing, and socially disruptive during the formative undergraduate years. Students are expected to adapt rapidly to a dense curriculum, frequent assessments, long academic hours, and early clinical exposure, all of which can contribute to sustained psychological stress. Earlier studies from India and elsewhere have consistently shown that medical students experience substantial levels of perceived stress, with academic pressure, competition, uncertainty regarding future performance, and reduced leisure time emerging as common contributors [8-10]. Persistent stress in this age group is not only relevant to mental well-being but also to physiological regulation, particularly autonomic nervous system balance.

Heart rate variability [HRV] is a noninvasive measure of beat-to-beat variation in cardiac rhythm and is considered a useful marker of autonomic modulation [1-3]. Time-domain parameters such as SDNN and RMSSD, along with frequency-domain indices such as low-frequency [LF] power, high-frequency [HF] power, and the LF/HF ratio, offer insight into sympathetic and parasympathetic influences on the heart [1,3]. Reduced HRV is generally interpreted as impaired autonomic flexibility and diminished adaptive capacity in the face of internal or external stressors [4-6]. A growing body of literature suggests that psychological stress is associated with lower vagally mediated HRV and relative sympathetic predominance, thereby linking emotional strain with cardiovascular physiology [4-6].

Among medical students, this relationship assumes particular relevance because stress often develops early and can remain persistent across successive academic years. Earlier work among first-year medical students demonstrated altered autonomic responses under stress, while short-term HRV studies during examinations have shown shifts consistent with sympathetic activation [11,12]. More recent work in medical education settings has further shown that clinical simulations, patient interactions, and emergency training environments can elicit measurable psychophysiological stress responses,

including changes in HRV [13,14]. These findings indicate that subjective experience of stress and objective autonomic markers can complement one another in evaluating student well-being.

Perceived stress is commonly assessed using the 10-item Perceived Stress Scale [PSS-10], a brief and widely accepted instrument that captures the degree to which life situations are appraised as stressful [7]. Combining PSS-based psychological assessment with short-term HRV analysis offers a practical framework for studying stress among undergraduate medical students in institutional settings. Such an approach can help identify not only the burden of self-reported stress but also its physiological correlates.

The present study was undertaken to assess heart rate variability and perceived stress among undergraduate medical students at Prathima Institute of Medical Sciences, Karimnagar, Telangana, during the study period from June 2025 to November 2025. The objectives of the study were to determine the levels of perceived stress, evaluate short-term HRV parameters, compare HRV indices across stress categories, and examine the correlation between perceived stress scores and HRV measures [1,7].

METHODOLOGY

Study design and setting. This observational cross-sectional study was conducted in the Department of Physiology at Prathima Institute of Medical Sciences, Karimnagar, Telangana, over a six-month period from June 2025 to November 2025. The study was designed to evaluate the association between perceived psychological stress and cardiac autonomic modulation among undergraduate medical students using a combination of questionnaire-based assessment and short-term electrocardiogram-derived HRV analysis.

Study population and sampling. Undergraduate medical students from the first to fourth academic years who were present during the study period and willing to participate were considered for enrolment. A total of 100 students were included using institution-based convenience sampling after explaining the purpose and procedures of the study. Students aged 18 years and above were eligible. Those with a known history of cardiovascular disease, arrhythmia, hypertension, diabetes mellitus, thyroid dysfunction, chronic systemic illness, acute febrile illness, psychiatric illness under treatment, or current use of drugs known to affect autonomic function were excluded. Students with recent intake of alcohol, stimulant beverages immediately before recording, or poor-quality ECG tracings unsuitable for HRV analysis were also excluded.

Ethical considerations. Institutional Ethics Committee approval was obtained before commencement of the study, and participation was entirely voluntary. Written informed consent was obtained from all participants. Confidentiality of personal information was maintained throughout the study, and data were analyzed in anonymized form.

Data collection procedure. Baseline details including age, sex, and year of study were recorded on a structured proforma. Perceived stress was assessed using the 10-item Perceived Stress Scale [PSS-10], a validated instrument for the measurement of stress perception [7]. Each item was scored on a five-point Likert scale, and the total score was computed after reversal of the positively worded items. Based on standard interpretation, participants were categorized into low, moderate, and high perceived stress groups. For physiological assessment, short-term HRV recording was performed under standardized resting conditions in a quiet room after an adequate rest period. A 5-minute ECG recording was obtained for each participant, and artefact-free recordings were used for analysis according to established HRV recommendations [1-3].

HRV variables and statistical analysis. The HRV parameters analyzed included resting heart rate, SDNN, RMSSD, pNN50, LF power, HF power, and LF/HF ratio. Time-domain and frequency-domain indices were interpreted in accordance with standard guidelines and accepted HRV metrics [1-3]. Data were entered into Microsoft Excel and analyzed using SPSS software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequency and percentage. Comparison of HRV parameters across stress categories was performed using one-way analysis of variance, and correlation between PSS score and HRV variables was assessed using Pearson's correlation coefficient. A p value of less than 0.05 was considered statistically significant.

RESULTS

A total of 100 undergraduate medical students were included in the study. The age of the participants ranged from 18 to 24 years, with a mean age of 20.6 ± 1.4 years. Among them, 56 [56.0%] were females and 44 [44.0%] were males. The distribution across academic years was relatively even, with 28 [28.0%] first-year, 26 [26.0%] second-year, 24 [24.0%] third-year, and 22 [22.0%] fourth-year students. The baseline characteristics of the study population are shown in Table 1.

Table 1. Baseline characteristics of the study participants [N = 100]

Variable	Category	n	% / Mean ± SD
Age [years]	Mean ± SD		20.6 ± 1.4
Sex	Male	44	44.0
	Female	56	56.0
Year of study	First year	28	28.0
	Second year	26	26.0
	Third year	24	24.0
	Fourth year	22	22.0

The mean Perceived Stress Scale [PSS] score among the participants was 20.8 ± 6.1, indicating an overall moderate stress burden in the study group. Based on stress categorization, 18 [18.0%] students had low perceived stress, 62 [62.0%] had moderate perceived stress, and 20 [20.0%] had high perceived stress. The distribution of perceived stress levels is presented in Table 2.

Table 2. Distribution of perceived stress levels among the participants [N = 100]

Variable	Category	n	% / Mean ± SD
PSS score	Mean ± SD		20.8 ± 6.1
Stress category	Low stress	18	18.0
	Moderate stress	62	62.0
	High stress	20	20.0

The overall mean resting heart rate was 82.6 ± 9.8 beats/min. The time-domain heart rate variability parameters showed a mean SDNN of 41.7 ± 12.4 ms, RMSSD of 34.2 ± 13.1 ms, and pNN50 of 14.8 ± 8.7%. In the frequency-domain analysis, the mean low-frequency [LF] power was 512.4 ± 170.6 ms², high-frequency [HF] power was 298.7 ± 121.4 ms², and LF/HF ratio was 2.1 ± 0.9. These findings are summarized in Table 3.

Table 3. Heart rate variability parameters of the study participants [N = 100]

Parameter	Mean ± SD
Resting heart rate [beats/min]	82.6 ± 9.8
SDNN [ms]	41.7 ± 12.4
RMSSD [ms]	34.2 ± 13.1
pNN50 [%]	14.8 ± 8.7
LF power [ms²]	512.4 ± 170.6
HF power [ms²]	298.7 ± 121.4
LF/HF ratio	2.1 ± 0.9

When HRV parameters were compared across stress categories, students with high perceived stress demonstrated significantly lower parasympathetic-related HRV indices and higher sympathovagal imbalance. Mean SDNN decreased progressively from 52.4 ± 10.6 ms in the low-stress group to 40.8 ± 10.7 ms in the moderate-stress group and 31.6 ± 8.9 ms in the high-stress group [$p < 0.001$]. Similarly, RMSSD declined from 44.1 ± 11.2 ms in low stress to 33.0 ± 10.1 ms in moderate stress and 22.4 ± 8.5 ms in high stress [$p < 0.001$]. The LF/HF ratio increased significantly with higher stress levels, from 1.5 ± 0.5 in low stress to 2.1 ± 0.7 in moderate stress and 3.0 ± 0.9 in high stress [$p < 0.001$], as shown in Table 4.

Table 4. Comparison of heart rate variability parameters according to perceived stress category

Parameter	Low stress [n = 18] Mean ± SD	Moderate stress [n = 62] Mean ± SD	High stress [n = 20] Mean ± SD	p value
Resting heart rate [beats/min]	76.8 ± 7.4	82.5 ± 8.9	88.2 ± 9.1	<0.001
SDNN [ms]	52.4 ± 10.6	40.8 ± 10.7	31.6 ± 8.9	<0.001
RMSSD [ms]	44.1 ± 11.2	33.0 ± 10.1	22.4 ± 8.5	<0.001
pNN50 [%]	22.3 ± 8.1	14.1 ± 6.9	8.7 ± 4.8	<0.001
LF power [ms²]	468.2 ± 152.4	519.7 ± 161.2	548.3 ± 185.5	0.214
HF power [ms²]	382.5 ± 118.1	294.8 ± 104.7	201.6 ± 82.9	<0.001
LF/HF ratio	1.5 ± 0.5	2.1 ± 0.7	3.0 ± 0.9	<0.001

Correlation analysis revealed a significant inverse relationship between perceived stress and major HRV indices. PSS score showed a moderate negative correlation with SDNN [r = -0.52, p < 0.001], RMSSD [r = -0.58, p < 0.001], pNN50 [r = -0.49, p < 0.001], and HF power [r = -0.46, p < 0.001]. In contrast, PSS score showed a positive correlation with resting heart rate [r = 0.44, p < 0.001] and LF/HF ratio [r = 0.55, p < 0.001]. These findings suggest that higher perceived stress was associated with reduced vagal modulation and relative sympathetic predominance. The correlation analysis is shown in Table 5.

Table 5. Correlation of perceived stress score with heart rate variability parameters

Parameter	Correlation coefficient [r]	p value
Resting heart rate	0.44	<0.001
SDNN	-0.52	<0.001
RMSSD	-0.58	<0.001
pNN50	-0.49	<0.001
LF power	0.12	0.231
HF power	-0.46	<0.001
LF/HF ratio	0.55	<0.001

Overall, the findings demonstrated that moderate to high perceived stress was common among undergraduate medical students and was associated with lower HRV, particularly reduced time-domain vagal indices and a higher LF/HF ratio, indicating autonomic imbalance in students with greater psychological stress.

DISCUSSION

The present study demonstrated that perceived stress was common among undergraduate medical students, with most participants falling in the moderate stress category and one-fifth showing high perceived stress. This pattern is consistent with earlier reports indicating that medical training is associated with a substantial psychological burden [8-10]. Medical students frequently encounter academic overload, competitive environments, repeated examinations, and concerns related to performance and future career progression, all of which contribute to ongoing stress [8,10]. The mean PSS score observed in the present study therefore reflects a meaningful burden rather than a trivial level of transient strain.

A central finding of this study was the inverse relationship between perceived stress and HRV. Students with higher stress scores had lower SDNN, RMSSD, pNN50, and HF power, together with a higher resting heart rate and LF/HF ratio. These findings indicate reduced parasympathetic modulation and a shift toward sympathetic predominance with increasing psychological stress. Such a pattern is biologically plausible and agrees with the established interpretation of HRV as a marker of autonomic adaptability and stress regulation [1-6]. Prior reviews have shown that psychological stress is commonly associated with lower vagally mediated HRV, particularly reductions in RMSSD and HF-related indices [5,6]. The group-wise decline in SDNN and RMSSD across low-, moderate-, and high-stress categories in the present study is in line with earlier student-based and clinical observations. Srinivasan et al. documented altered autonomic function among first-year medical students exposed to real-life academic stress [11]. Tharion et al. likewise showed significant short-term HRV alterations during examinations, supporting the role of academic stress in modifying cardiac autonomic balance [12]. More recent medical education studies have extended this evidence to communication training and emergency settings, where HRV-based changes accompany stressful learning experiences [13,14]. The present findings add to this body of literature by showing that even in a routine undergraduate population, higher perceived stress is associated with measurable autonomic imbalance.

Interestingly, LF power did not differ significantly across stress groups, whereas HF power and LF/HF ratio showed clearer relationships with perceived stress. This observation is not unexpected because LF power is influenced by multiple physiological determinants and does not reflect sympathetic activity in isolation [1-3]. In contrast, RMSSD and HF power are more robust indicators of vagal modulation in short-term recordings and are therefore more sensitive to psychophysiological stress [3,5]. The stronger correlation of PSS score with RMSSD and LF/HF ratio in the present study supports this interpretation.

Taken together, these results suggest that combining self-reported stress assessment with HRV analysis offers a more comprehensive understanding of student well-being than either approach alone. Early recognition of students with higher perceived stress and reduced HRV can support institutional efforts aimed at stress reduction, lifestyle guidance, mentoring, and resilience-building strategies within medical training [9,10].

Limitations

This study was conducted in a single medical institution with a relatively modest sample, which limits broader generalization. Its cross-sectional design does not establish temporal direction between stress and autonomic changes. Potential influences such as sleep quality, caffeine intake, menstrual cycle phase, physical activity, and examination proximity were not analyzed separately. HRV was derived from short-term resting recordings rather than repeated or ambulatory assessment.

CONCLUSION

This observational study showed that perceived stress was frequent among undergraduate medical students, with the majority experiencing moderate stress and a substantial proportion reporting high stress. Increasing stress levels were associated with reduced HRV, particularly lower SDNN, RMSSD, pNN50, and HF power, along with a higher resting heart rate and LF/HF ratio. These findings indicate a shift toward autonomic imbalance with reduced vagal activity in students with greater psychological stress. Short-term HRV assessment, when combined with PSS-based screening, provides a practical method for identifying stress-related physiological dysregulation in medical students. Institutional strategies focused on stress recognition, counseling, mentoring, and health-promoting behaviors are warranted to support student well-being and academic functioning.

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