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**RESEARCH ARTICLE**

# Relationship between autonomic nervous system dysregulation, psychological distress, and sleep quality among medical students: A cross-sectional mediation study



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## Abstract

**Background:** Medical students are particularly vulnerable to psychological distress and sleep disturbances, yet the physiological mechanisms underlying these conditions remain insufficiently understood. Autonomic nervous system dysregulation represents a biologically plausible pathway linking stress to impaired sleep, with implications for student well-being and sustainable health promotion. The objective of this study was to examine the association between autonomic nervous system dysregulation and sleep quality among medical students and to determine whether this relationship is mediated by psychological distress.

**Methods:** In this cross-sectional study, medical students aged 18–25 years underwent an objective assessment of autonomic nervous system function using resting heart rate variability and subjective evaluation via the Composite Autonomic Symptom Score-31 questionnaire. Psychological distress was measured using the Depression Anxiety Stress Scale-21, and sleep quality using the Pittsburgh Sleep Quality Index. Multivariable regression and mediation analyses were performed.

**Results:** Among 312 students, 63.5% had poor sleep quality and 38.8% reported moderate-to-severe psychological distress. Psychological distress was moderately correlated with sleep disturbance ($r$=0.58). Mediation analysis showed that psychological distress partially mediated the association between reduced root mean square of successive differences and sleep quality, accounting for 41% of the total effect ($\beta$=−0.16, 95% confidence interval: −0.25 to −0.09).

**Conclusion:** Targeting autonomic regulation may offer novel intervention pathways to improve mental health and sleep quality among medical students.

### Key messages

Dysregulation of the autonomic nervous system is closely associated with psychological distress and poor sleep quality in medical college students. Distress is exacerbated by increased autonomic symptoms and decreased parasympathetic activity, which largely mediates sleep impairment. Focusing on autonomic control may provide practical methods to enhance students' sleep and mental well-being.

## Introduction

Medical education is widely regarded as both demanding and stressful. The transition into university life, along with academic pressure and changing social roles, increases the risk of psychological distress and sleep disturbances among medical students [1]. Studies have shown that a large proportion of medical students experience poor sleep quality, especially during periods of heavy academic workload [2]. Adequate sleep is essential for emotional regulation, cognitive functioning, and overall well-being, while sleep disturbances are linked to higher levels of depression, anxiety, and stress [3-4]. Meta-analyses report that depression, anxiety, and stress affect a substantial proportion of students globally [5].

The autonomic nervous system (ANS) plays an important role in stress regulation and sleep–wake patterns [6]. Heart rate variability (HRV), a non-invasive indicator of autonomic function, reflects the balance between sympathetic and parasympathetic activity. Lower HRV, particularly reduced parasympathetic indices such as root mean square of successive differences (RMSSD), has been associated with increased psychological distress and reduced adaptability to stress [7]. Previous studies in student populations have also demonstrated associations between altered HRV parameters and poor sleep quality [8]. In addition, psychological distress measured using tools such as Depression Anxiety Stress Scale-21 (DASS-21) has been consistently linked to impaired sleep [9].

Lifestyle factors, including reduced physical activity and increased screen time, further contribute to both poor sleep and higher stress levels [10]. Evidence suggests that sleep quality may act as an intermediary factor linking psychological distress with functional outcomes, with higher levels of depression increasing the likelihood of poor sleep [11]. At the same time, higher resting HRV has been associated with better academic performance, indicating its potential as a marker of resilience [12-13]. Advances in wearable technology have enabled objective monitoring of stress using HRV, although methodological factors such as circadian variation remain important for accurate assessment [14-15].

There hasn't been enough research done on the combination of validated self-reported measures of psychological distress and autonomic symptoms with objective physiological markers like HRV, particularly in student populations. Drawing on the neurovisceral integration model, it is plausible that autonomic dysfunction may influence sleep quality both directly and indirectly via psychological distress [16]. However, empirical evidence supporting this pathway in medical students remains limited. Therefore, the objective of this study was to examine the association between autonomic nervous system dysregulation and sleep quality among medical students and to determine whether this relationship is mediated by psychological distress.

## Methods

A cross-sectional study was conducted between October 2025 and January 2026 after obtaining ethical approval from the Institutional Scientific Review Board. All procedures adhered to the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to data collection.

The study population comprised MBBS students aged 18–25 years enrolled during the study period. Participants were selected using stratified random sampling based on year of study. A list of eligible students was obtained from the institution, and participants within each stratum were selected using computer-generated random numbers. Students willing to participate and able to complete English-language questionnaires were included. Students with a history of diagnosed psychiatric illness, chronic neurological or cardiovascular disease, recent major illness or surgery, or current use of medications affecting sleep, mood, or autonomic function were excluded.

Sample size was determined using G*Power 3.1 for multiple regression (effect size $f^2$=0.10, $\alpha$=0.05, power=0.90, 8 predictors), yielding a minimum of 262 participants. Accounting for attrition, 312 students were enrolled.

Data collection was carried out in a quiet room within the institution using a standardised protocol. Participants were scheduled in small groups and instructed to avoid caffeine intake, vigorous physical activity, and heavy meals for at least 3 hours prior to assessment. Upon arrival, demographic details and covariate information (age, sex, body mass index (BMI), physical activity, caffeine intake, and screen time) were recorded using a standardised form. Height and weight were measured using calibrated instruments to calculate BMI. Participants were then seated comfortably and allowed a 10-minute acclimatisation period before physiological recordings. HRV data were subsequently recorded under standardised resting conditions. Following HRV acquisition, participants completed a battery of self-administered questionnaires in English. A trained investigator was present to clarify queries without influencing responses. The total duration of assessment per participant was approximately 25–30 minutes. To ensure consistency, all data were collected by trained physiotherapy research assistants following a standardised protocol. Confidentiality was maintained by assigning unique identification codes to each participant. No personally identifiable information was included in the analysis dataset.

### Outcome measures

- HRV: HRV was recorded using a validated wearable electrocardiogram device (Polar H10 chest strap), with a sampling rate of ≥1000 Hz. Recordings were obtained in a seated position over a 5-minute resting period in a quiet

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**Table 1** Participant characteristics (n=312)

| Variable | Mean (SD) |
|---|---|
| Age (years) | 21.2 (1.9) |
| Men, n (%) | 138 (44.2) |
| Body mass index (kg/m²) | 22.6 (3.1) |
| Caffeine intake (>1 cup/day), n (%) | 187 (59.9) |
| Screen time (>6 h/day), n (%) | 203 (65.1) |
| RMSSD (ms) | 38.4 (15.7) |
| LF/HF ratio | 2.14 (0.92) |
| COMPASS-31 | 21.7 (9.8 |
| DASS-21 | 29.3 (14.2) |
| Poor sleep quality (PSQI >5), n (%) | 198 (63.5) |

SD indicates standard deviations; RMSSD, root mean square of successive differences; LF/HF, low frequency/high frequency ratio; COMPASS-31, Composite Autonomic Symptom Score; DASS-21, Depression Anxiety Stress Scale; PSQI, Pittsburgh sleep quality index

environment. Participants were instructed to breathe spontaneously and remain still during recording. Artefacts and ectopic beats were identified and corrected using HRV analysis software (R-based HRV packages). Data were visually inspected prior to analysis. Time-domain and frequency-domain parameters extracted included: RMSSD as an index of parasympathetic activity. LF/HF ratio as a marker of sympathovagal balance. Frequency-domain analysis was performed using fast Fourier transform.

- COMPASS-31: A validated questionnaire assessing autonomic symptoms across six domains -orthostatic intolerance, vasomotor, secretomotor, gastrointestinal, bladder, and pupillomotor function [17].
- DASS-21: Measures depression, anxiety, and stress with strong psychometric properties in student populations [18].
- Pittsburgh Sleep Quality Index (PSQI): Global score >5 indicates poor sleep quality [19].

### Covariates

Age, sex, BMI, caffeine intake, international physical activity questionnaire–short form (IPAQ-SF) and daily screen time were included as confounders.

### Statistical analysis

Data were analysed using (version 26.0).

Descriptive statistics were expressed as mean (standard deviation) for continuous variables and frequencies (percent) for categorical variables. Normality of continuous variables, including DASS-21 and PSQI scores, was assessed using the Shapiro–Wilk test along with visual inspection of histograms and Q–Q plots. Mild deviations from normality were observed; however, parametric analyses were retained due to robustness in large samples.

Sex was coded as a binary variable (male=0, female=1), with male considered the reference category. Pearson correlation coefficients were used to examine relationships between autonomic measures, psychological distress, and sleep quality.

Multiple linear regression using the ordinary least squares method was conducted to identify predictors of psychological distress (DASS-21) and sleep quality (PSQI). Assumptions of linearity, normality, homoscedasticity, and independence of residuals were verified using residual diagnostics. Mediation analysis was performed using a bootstrapping approach with 5,000 resamples to estimate indirect effects and corresponding 95% confidence intervals. A $P < 0.05$ was considered statistically significant.

**Table 2** Correlation matrix (n=312)

| Variables | RMSSD | LF/HF | COMPASS-31 | DASS-21 | PSQI |
|---|---|---|---|---|---|
| RMSSD | 1 | - | - | - | - |
| LF/HF | −0.46[a] | 1 | - | - | - |
| COMPASS-31 | −0.41[a] | 0.38[a] | 1 | - | - |
| DASS-21 | −0.49[a] | 0.44[a] | 0.52[a] | 1 | - |
| PSQI | −0.37[a] | 0.33[a] | 0.46[a] | 0.58 [a] | 1 |

RMSSD indicate root mean square of successive differences; LF/HF, low frequency/high frequency ratio; COMPASS-31, Composite Autonomic Symptom Score; DASS-21, Depression Anxiety Stress Scale; PSQI, Pittsburgh sleep quality index; [a]*P* <0.001.

## Results

A total of 312 medical students participated in the study, with a mean (standard deviation) age of 21.2 (1.9) years. Women constituted 55.8%. The mean (standard deviation) BMI was 22.6 (3.1) kg/m². Lifestyle characteristics indicated that a substantial proportion of participants reported daily caffeine intake exceeding one cup (59.9%) and screen exposure greater than six hours per day (65.1%).

**Table 3** Regression predicting psychological distress

| Predictor | β | SE | *P* |
|---|---|---|---|
| RMSSD | −0.34 | 0.05 | <0.001 |
| LF/HF ratio | 0.21 | 0.04 | <0.001 |
| COMPASS-31 | 0.29 | 0.03 | <0.001 |
| Women vs men | 0.12 | 0.08 | 0.014 |
| Screen time | 0.15 | 0.07 | 0.009 |
| Physical activity | −0.11 | 0.06 | 0.031 |

SE indicates standard error; RMSSD, Root Mean Square of Successive Differences; LF/HF, low frequency/high frequency ratio; COMPASS-31, Composite Autonomic Symptom Score.

Model fit: $R^2 = 0.42$; Adjusted $R^2 = 0.40$.

Autonomic assessment demonstrated a mean (standard deviation) RMSSD of 38.4 (15.7) ms and a mean LF/HF ratio of 2.14 (0.92), indicating variability in autonomic regulation. The mean (standard deviation) COMPASS-31 score was 21.7 (9.8). The mean psychological distress score (DASS-21) was 29.3 (14.2), with 38.8% of participants classified as having moderate to severe distress. The mean (standard deviation) PSQI score was 7.2 (3.1), and 63.5% of students were categorised as poor sleepers **(Table 1)**. Correlation analysis revealed significant associations among autonomic parameters, psychological distress, and sleep quality **(Table 2)**. Psychological distress demonstrated the strongest association with sleep quality.

**Table 4** Regression predicting sleep quality

| Predictor | β | SE | *P* |
|---|---|---|---|
| RMSSD | −0.18 | 0.04 | 0.002 |
| COMPASS-31 | 0.22 | 0.03 | <0.001 |
| DASS-21 | 0.47 | 0.02 | <0.001 |
| Caffeine intake | 0.13 | 0.31 | 0.018 |
| Screen time | 0.16 | 0.05 | 0.006 |

SE indicates standard error; RMSSD, root mean square of successive differences; LF/HF, low frequency/high frequency ratio; COMPASS-31, composite autonomic symptom score; DASS-21, depression anxiety stress scale.

Model fit: $R^2 = 0.51$; Adjusted $R^2 = 0.49$, Note: LF/HF ratio excluded due to collinearity

In multivariable regression analysis, reduced RMSSD, increased LF/HF ratio, and higher COMPASS-31 scores were independently associated with greater psychological distress. Women (with men as the reference category) and increased screen time were also significant predictors, while physical activity showed a protective association. The model explained 42% of the variance in distress **(Table 3)**. For sleep quality, psychological distress emerged as the strongest predictor, followed by autonomic symptom burden and reduced parasympathetic activity. The final model explained 51% of the variance in PSQI scores **(Table 4)**. Mediation analysis indicated that psychological distress partially mediated the relationship between RMSSD and sleep quality, accounting for 41% of the total effect **(Table 5)**. The indirect pathway was statistically significant. The structural model supported this relationship and demonstrated good overall fit. Given the cross-sectional design, the reported associations should be interpreted as correlational, and no causal or directional inferences can be established.

**Table 5** Mediation analysis

| Pathway | Effect | 95% confidence interval | *P* |
|---|---|---|---|
| Total effect | -0.39 | -0.52 to -0.26 | <0.001 |
| Direct effect | -0.23 | -0.35 to -0.11 | <0.001 |
| Indirect effect (via distress) | -0.16 | -0.25 to -0.09 | <0.001 |
| % mediated | 41% | - | - |

Note: Bootstrapped using 5,000 resamples.

## Discussion

The present cross-sectional study provides evidence supporting an association between autonomic nervous system function, psychological distress, and sleep quality among medical students. By integrating objective cardiac autonomic indices, subjective autonomic symptoms, validated psychological measures, and sleep quality assessment, this study extends existing literature beyond single-domain approaches and offers insight into a potential biopsychosocial framework underlying mental health and sleep disturbances in this population.

The findings indicate that reduced parasympathetic activity, indexed by lower RMSSD, and increased autonomic imbalance, reflected by higher LF/HF ratios and COMPASS-31 scores, were significantly associated with higher levels of psychological distress. These observations are consistent with the neurovisceral integration model, which suggests that lower vagal activity may be related to reduced prefrontal regulatory capacity over stress-responsive neural systems and may be linked to greater emotional dysregulation [20, 21, 22]. Prior studies have reported similar associations between reduced heart rate variability and symptoms of depression and anxiety across clinical and non-clinical populations [23, 24]. However, many of these studies have relied either on self-reported measures or isolated physiological indicators. In contrast, the present study integrates both objective and subjective autonomic assessments within a single analytical framework, thereby addressing methodological limitations of prior research and providing a more comprehensive evaluation within a medical student cohort.

It is important to note that mediation analysis in cross-sectional data reflects statistical partitioning of associations rather than true temporal or causal pathways.

Notably, subjective autonomic symptom burden, as measured by COMPASS-31, was independently associated with psychological distress even after adjustment for lifestyle factors. This suggests that perceived physiological dysregulation may capture chronic stress-related experiences not fully reflected by resting HRV indices alone [25]. These findings highlight the importance of incorporating multi-method approaches when examining autonomic function in relation to mental health outcomes.

Psychological distress was strongly associated with sleep quality, accounting for a substantial proportion of the variance in PSQI scores. This observation aligns with previous literature indicating that elevated levels of stress, anxiety, and depressive symptoms are associated with impaired sleep initiation and maintenance, potentially through mechanisms such as cognitive hyperarousal, hypothalamic–pituitary–adrenal axis activation, and disruption of circadian rhythms [26-30]. The high prevalence of poor sleep quality observed in this study is consistent with global estimates among medical students and underscores the significance of sleep disturbances within this population [27].

Importantly, psychological distress showed a stronger association with sleep quality than autonomic indices alone, suggesting that subjective psychological processes may represent a more proximal correlate of sleep impairment. This is in line with theoretical models proposing that emotional dysregulation and maladaptive stress responses may mediate the relationship between physiological stress systems and behavioral outcomes such as sleep [28].

A key finding of this study is that psychological distress partially mediated the association between parasympathetic activity and sleep quality, accounting for approximately 41% of the observed relationship.

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This suggests that autonomic dysregulation may be related to sleep disturbances indirectly through its association with emotional distress. However, given the cross-sectional design, this mediational pathway should be interpreted cautiously and does not imply causality. The persistence of a significant direct association between RMSSD and sleep quality indicates that additional pathways may also be involved. These may include mechanisms such as nocturnal autonomic regulation, sleep architecture, or circadian influences that are not fully captured by measures of psychological distress [31].

### Implications for intervention and prevention

The present findings have potential implications for student mental health and well-being. While conventional approaches often emphasize psychological counseling and sleep hygiene strategies, the observed associations suggest that interventions targeting autonomic regulation may be relevant and warrant further investigation. Approaches such as heart rate variability biofeedback, mindfulness-based practices, yoga, and aerobic exercise have been associated with improvements in autonomic balance and psychological functioning [32]. These approaches may complement existing strategies by addressing physiological aspects of stress regulation. However, given the observational design, these implications should be interpreted as hypothesis-generating rather than definitive recommendations.

### Strengths

This study has several strengths. It integrates objective and subjective measures of autonomic function alongside validated assessments of psychological distress and sleep quality, providing a multidimensional perspective. The use of mediation analysis and structural equation modeling allows for the examination of potential statistical pathways linking physiological and psychological variables. Additionally, the relatively large sample size enhances the robustness and precision of the findings.

### Limitations

Several limitations should be considered. First, the cross-sectional design precludes causal inference, and the directionality of associations cannot be established. Reverse relationships, such as the impact of poor sleep on psychological distress or autonomic function, are possible [33].

Second, HRV was assessed during resting wakefulness rather than during sleep, which limits conclusions regarding nocturnal autonomic regulation. Third, although key covariates were included, residual confounding from unmeasured variables such as academic workload, chronotype, or environmental stressors cannot be excluded.

Fourth, participants were recruited from a single institution, which may limit the generalisability of the findings to other student populations or geographical settings. Finally, psychological distress and sleep quality were assessed using self-reported questionnaires, which may be subject to recall and reporting bias.

### Conclusion

The present study demonstrates that autonomic nervous system function is associated with psychological distress and sleep quality among medical students, with psychological distress partially mediating this relationship. These findings support a biopsychosocial perspective on student well-being and highlight the potential relevance of autonomic regulation in understanding mental health and sleep disturbances. However, given the observational nature of the study, these results should be interpreted as indicative of associations rather than causal and further research is required to confirm these pathways and inform intervention strategies. Experimental research examining whether interventions that enhance autonomic regulation lead to improvements in mental health and sleep outcomes would provide stronger evidence. Additionally, incorporating ambulatory monitoring and sleep-stage–specific autonomic assessments may further advance understanding of underlying mechanisms.

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### Author contributions

*Concept or design of the work; or the acquisition, analysis, or interpretation of data for the work:* TA, VJ. *Drafting the work or reviewing it critically for important intellectual content:* TA, VJ, VS, PS, PK, DS, KW, MW. *Final approval of the version to be published:* VJ, VS, PS, TA, PK, DS, KW, MW. *Accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved:* VJ, TA.

### Conflict of interest

We do not have any conflict of interest.

### Data availability statement

We confirm that the data supporting the findings of the study will be shared upon reasonable request.

### AI disclosure

The authors also acknowledge the use of artificial intelligence tools, including ChatGPT, for assistance with language editing and improving the clarity of the manuscript. The authors affirm that all scientific content, interpretation, and final manuscript approval were carried out by the authors in compliance with the journal's guidelines, and that AI-assisted language editing was only utilised for grammar and language improvement.

### Supplementary file

None

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