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Research Article

Altered sleep architecture in chronic insomnia and its phenotypes: polysomnographic correlates and associations with insomnia severity and depressive symptoms

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Abstract

Aim: The aim of this study was to evaluate clinical and polysomnographic differences in sleep architecture between patients with chronic insomnia (CI) and healthy controls (HC), as well as between CI phenotypes with short and normal sleep duration.

Materials and methods: This cross-sectional study included 35 patients with CI and 27 age- and sex-matched HC. All participants completed the Insomnia Severity Index (ISI) and Beck Depression Inventory (BDI) and underwent single-night home polysomnography. Based on 14-day sleep diaries, patients were categorized into insomnia with self-reported short sleep duration (ISSD; <6 h) and insomnia with self-reported normal sleep duration (INSD; ≥6 h). Group comparisons and correlation analyses were performed.

Results: Compared with HC, CI patients showed significantly higher ISI and BDI scores, increased total wake time (TWT), wake after sleep onset (WASO), and N2 sleep duration, along with reduced N3 sleep and sleep efficiency (SE). No significant differences were observed in total sleep time or sleep latency. ISSD patients demonstrated significantly higher questionnaire scores, shorter TST, and reduced REM sleep compared with INSD. ISI correlated positively with BDI, TWT, SL, and WASO and negatively with sleep efficiency.

Conclusion: CI is associated with objective alterations in sleep architecture, particularly increased nocturnal wakefulness and reduced deep sleep. The ISSD phenotype appears clinically more severe, with greater symptom burden and reduced REM sleep, supporting the value of combining subjective and objective measures in insomnia phenotyping.

Keywords

objective sleep measures, short sleep duration, sleep macrostructure, sleep phenotyping, sleep state misperception

Introduction

The third edition of the International Classification of Sleep Disorders (ICSD-III) identifies chronic insomnia (CI) as a diagnostic category on its own, rather than a core symptom of impaired sleep.[1] CI is positioned as an important public health concern, commonly associated with somatic and/or psychiatric diseases, with the relation oftentimes being bidirectional.[2,3] The established diagnostic algorithm for CI is based on comprehensive general medical and sleep-focused history (standard, high level of recommendation).[1,4] Polysomnography (PSG) is not indicated for the routine evaluation of CI, yet objectively measured PSG parameters have provided new insights into CI phenotypes.[5]

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The main PSG findings in CI include reduced total sleep time (TST), prolonged sleep latency (SL), shortened deep sleep (N3), and increased frequency of micro-arousals.[6,7] Despite these consistent findings, some authors report no statistically significant differences in objectively measured sleep duration or SL between patients and healthy controls, though subjective reports indicate shorter TST and prolonged SL, reflecting the phenomenon of sleep state misperception (SSM).[8] Additionally, several authors have identified features characteristic of disturbed REM sleep in CI.[9,10] These findings, collectively referred to as "REM sleep instability," are characterized by shortened and fragmented REM, which may represent a substrate for SSM, as it promotes increased vulnerability to both internal and external arousing stimuli.[11]

Contemporary classification divides CI into (1) acute, (2) chronic, and (3) other CI disorder types, reflecting only symptom duration without considering objective measurements and severity.[1] Alternatively, classifications based on objectively measured PSG parameters have provided new insights into CI phenotypes. In concordance with these findings, Vgontzas et al. proposed a classification for CI dividing patients into two phenotypes, based on TST: (1) insomnia with short sleep duration (ISSD; TST <6 hours) and (2) insomnia with normal sleep duration (INSD; TST ≥6 hours).[12] There is a growing body of evidence demonstrating that ISSD is associated with higher health concerns and is the biologically more severe phenotype, related to increased risk of cardiovascular diseases, chronic proinflammatory state, and metabolic alterations, while INSD is more strongly associated with anxiety, rumination, and sleep misperception.[13-15] Collectively, these findings support the subdivision of CI into phenotypes based on TST, with important implications for clinical practice and research.

All of the above suggest that while modern sleep research defines CI as a subjective disturbance of sleep continuity accompanied by daytime impairments, it is also associated with objective physiological abnormalities. Accordingly, CI is a neurobiological disorder rather than simply a perception of poor sleep; thus, objective methods validating dysfunctional sleep are required.[5,16] Investigating both objective and subjective sleep parameters may improve understanding of CI's heterogeneity.

Aim

The aim of this study was to evaluate clinical and PSG differences in sleep architecture between CI patients and healthy controls, as well as within the insomnia phenotypes with short and normal sleep duration.

Materials and methods

This observational, cross-sectional study was performed at the Medical University of Plovdiv, Bulgaria, and approved by the local ethics committee (approval No. HO-11/2021). We recruited 35 CI patients (11 males) and 27 age- and sex-matched HC (9 males). Written informed consent was obtained from all subjects. Participants filled out questionnaires assessing CI symptoms (Insomnia Severity Index, ISI), daytime consequences (Epworth Sleepiness Scale, ESS), and depressive traits (Beck Depression Inventory, BDI). Based on self-reported sleep duration from 14-day sleep diaries, patients were divided into ISSD and INSD groups, with a cut-off set at 6 hours of subjective TST.

Eligibility was based on the following inclusion criteria: (1) age between 18 and 65 years and (2) meeting diagnostic criteria for CI, according to ICSD-III (for the patients' group). The following exclusion criteria were applied: (1) concomitant sleep disorder; (2) clinically significant psychiatric impairment; (3) intake of psychoactive drugs; (4) shift work; (5) somatic diseases, significantly worsening sleep quality and quantity; and (6) neurologic diseases.

All participants underwent a structured clinical and sleep-focused interview and a single-night, unattended, home-based PSG using a portable NOX A1 system (Reykjavík, Iceland). The montage included electroencephalography (EEG), electrooculography, submental electromyography, lower limb movements, electrocardiography, respiratory airflow and effort, and oxygen saturation (SpO_2). Recordings were manually scored in accordance with version 2.3 of the American Academy of Sleep Medicine criteria. The primary PSG-derived parameters included SL, TST, time in bed (TIB), sleep efficiency (SE), sleep stage duration (N1, N2, N3, and REM), total wake time (TWT), wake after sleep onset (WASO), and REM latency.

Statistical analysis of all the demographic and clinical data was conducted using SPSS 25.0 (IBM Corp., Armonk, NY, USA) for Windows. Normality of distribution was tested using the Shapiro–Wilk test. Demographic characteristics were compared using Student's *t*-test or chi-square test. Questionnaire results and PSG-derived sleep parameters were compared using the Mann–Whitney U test. Correlations were performed using Spearman's correlation method. The level of statistical significance was set at $p<0.05$.

Results

Clinical data

Statistical analyses revealed that CI patients and HC did not differ significantly in terms of age, sex, and education level. Both ISI and BDI results are significantly higher in the CI group compared to HC ($p<0.001$). Albeit reporting daytime sequelae and fatigue, no significant difference in sleepiness was observed between groups when assessed with ESS ($p=0.177$). PSG data revealed significantly higher TWT ($p<0.001$), WASO ($p<0.001$), and N2 stage ($p=0.002$), with decreased N3 ($p=0.026$) and SE ($p=0.014$) in the CI group compared to HC. No statistically significant difference was

observed in the TST (p=0.143) and SL (p=0.109) **(Fig. 1A)**. All demographic and clinical data are presented in **Table 1**.

To further explore clinical and PSG differences between CI phenotypes, we subdivided the patients' cohort into two subgroups based on the subjectively reported TST from their sleep logs - "insomnia with normal sleep duration" (INSD), TST >6 h, and "insomnia with short sleep duration" (ISSD), TST <6 h. The two subgroups did not differ significantly in terms of age, sex, and level of education. The ISSD group showed significantly higher scores on both ISI (p=0.029) and BDI (p=0.045) questionnaires. Statistical analyses of PSG revealed shortened TST in the ISSD group (p=0.003), confirming reduced sleep duration in this group, as well as significantly decreased REM sleep duration (p=0.029) **(Fig. 1B)**. All demographic and clinical data for both subgroups are presented in **Table 2**.

Table 1. Demographic and clinical data

Variable	Patients (n = 35) Median (IQR)	Healthy controls (n = 27) Median (IQR)	*p*-value [U]
Age	36.00 (26.00 – 46.00)	29.00 (24.00 – 39.00)	0.102
Sex F/M	24/11	18/9	0.874 [χ2]
Education level n (%)			
Higher	22 (52.40%)	20 (47.60%)	0.349 [χ2]
Secondary	13 (65.00%)	7 (35.00%)	
ISI	18.00 (15.00 -22.00)	3.00 (1.00 – 4.00)	**<0.001**
BDI	13.00 (6.00 – 20.00)	5.00 (1.00 – 7.00)	**<0.001**
ESS	3.00 (1.00 – 7.00)	4.00 (3.00 – 7.00)	0.177
TST (min)	397.10 (282.00 – 427.50)	368.00 (326.30 – 368.00)	0.143
TWT (min)	85.80 (44.30 – 117.10)	41.05 (28.45 – 60.55)	**<0.001**
N1 (min)	4.00 (3.00 – 7.00)	2.75 (1.38 – 7.00)	0.228
N2 (min)	218.50 (191.10 – 252.00)	168.50 (149.88 – 210.50)	**0.002**
N3 (min)	80.50 (62.50 – 116.00)	108.00 (83.36 – 133.25)	**0.026**
REM (min)	71.00 (55.50 – 85.00)	75.75 (51.88 – 89.25)	0.815
SL (min)	13.30 (5.90 – 27.20)	10.55 (6.75 – 17.03)	0.109
WASO (min)	62.90 (34.90 – 95.60)	25.65 (17.80 – 49.48)	**<0.001**
SE (%)	83.20 (77.00 – 89.80)	89.00 (84.00 – 93.40)	**0.014**
AHI	1.80 (1.20 – 3.20)	2.55 (1.70 – 3.83)	0.118

[U]: Mann–Whitney U test; [χ2]: chi-square test; IQR: interquartile range; ISI: insomnia severity index; BDI: Beck depression inventory; ESS: Epworth sleepiness scale; TST: total sleep time; TWT: total wake time; N1, N2, N3, REM: sleep stages; SL: sleep latency; WASO: wake after sleep onset; SE: sleep efficiency; AHI: apnea-hypopnea index

Table 2. Demographic and clinical data for insomnia subgroups

Variable	ISSD (n=17) Median (IQR)	INSD (n=18) Median (IQR)	*p*-value [U]
Age	39.00 (25.00 – 47.00)	35.00 (26.00 – 45.25)	0.684
Sex F/M	12/5	12/6	0.874 [χ2]
Education level n (%)			
Higher	10 (45.50%)	12 (54.50%)	0.803 [χ2]
Secondary	7 (53.80%)	6 (46.20%)	
ISI	20.00 (16.00 - 23.00)	18.00 (14.75 – 18.00)	**0.029**
BDI	18.00 (9.00 – 22.00)	11.50 (5.50 – 14.25)	**0.045**
ESS	3.00 (1.00 – 5.00)	4.00 (1.75 – 8.00)	0.351
TST (min)	364.50 (287.75 – 405.00)	416.75 (385.08 – 439.53)	**0.003**
TWT (min)	93.40 (53.30 – 122.55)	73.45 (38.75 – 110.28)	0.245
N1 (min)	5.50 (3.00 – 7.25)	4.00 (2.88 – 5.86)	0.424
N2 (min)	208.00 (166.25 – 241.75)	229.50 (201.98 – 265.75)	0.062
N3 (min)	78.00 (51.75 – 95.00)	88.75 (51.75 – 122.75)	0.083
REM (min)	60.50 (49.50 – 73.50)	80.00 (63.86 – 92.88)	**0.029**
SL (min)	21.10 (7.65 – 35.10)	11.80 (4.13 – 26.78)	0.369
WASO (min)	81.10 (37.25 – 100.30)	50.40 (30.50 – 95.50)	0.195
SE (%)	80.40 (72.15 – 85.95)	84.55 (78.73 – 91.00)	0.089
AHI	1.50 (0.75 – 2.05)	2.50 (1.80 – 4.00)	**0.022**

ISSD: Insomnia with short sleep duration; INSD: insomnia with normal sleep duration; U: Mann-Whitney U test; χ2: Chi-square test; IQR: Interquartile range; ISI: Insomnia severity index; BDI: Beck depression inventory; ESS: Epworth sleepiness scale; TST: total sleep time; TWT: total wake time; N1, N2, N3, REM: sleep stages; SL: Sleep latency; WASO: wake after sleep onset; SE: Sleep efficiency; AHI: Apnea-hypopnea index;

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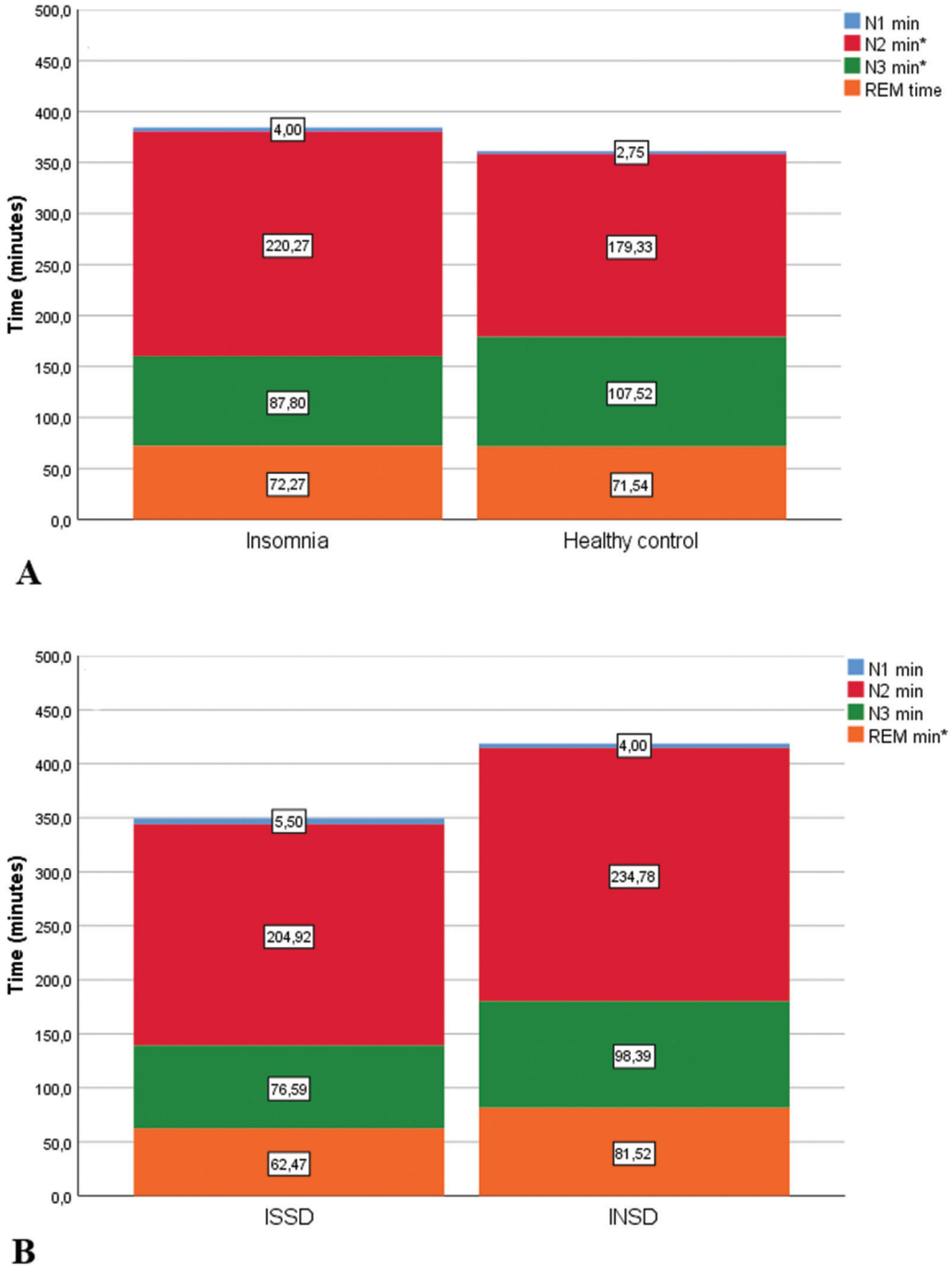

Figure 1. Polysomnographic differences in sleep architecture between (**A**) Insomnia patients and healthy controls; (**B**) Insomnia with short (ISSD) and normal (INSD) sleep duration. * $p<0.05$.

Statistical analysis

Correlations were assessed using Spearman's rank correlation coefficient (rho). The results obtained from objective clinical measures were correlated with the questionnaire's scores. The analysis revealed a significant positive correlation between the total scores of ISI and BDI (rho=0.735, $p<0.001$), indicating a strong association between insomnia severity and the depressive profile of the individuals. In addition, ISI showed a positive correlation with TWT (rho=0.568, $p<0.001$) as well as with WASO (rho=0.526, $p<0.001$), suggesting a strong relationship between subjectively reported insomnia severity and objectively measured wakefulness. TWT was also positively correlated with BDI scores (rho=0.327, $p=0.010$), indicating an association between increased wakefulness and depressive symptomatology. Furthermore, a moderate correlation was observed between BDI and TWT (rho=0.337, $p=0.008$).

A moderate correlation was also identified between ISI and SL (rho=0.267, p=0.038). In addition, a negative correlation was found between SE and ISI (rho= −0.405, p=0.001). Analyses of correlations among PSG parameters demonstrated a negative association between TWT and N3 duration (rho= −0.349, p=0.006), N2 and N3 duration (rho = −0.477, p<0.001), whereas REM duration was positively correlated with TST (rho=0.629, p<0.001). A detailed presentation of correlation strengths is provided in **Table 3**.

Table 3. Correlation strengths between PSG data and questionnaire scores

Correlation	Spearman's rho	Significance (p)
ISI – BDI	0.735	**<0.001**
ISI – TWT	0.568	**<0.001**
ISI – SL	0,267	0.038
ISI – WASO	0,526	**<0.001**
ISI – SE	−0.405	**0.001**
BDI – TWT	0.337	0.008
BDI – WASO	0.327	0.010
N3 – WASO	−0.349	0.006
N2 – N3	−0.477	**<0.001**
TST – REM	0.629	**<0.001**

PSG: polysomnography; ISI: insomnia severity index; BDI: Beck depression inventory; TWT: total wake time; SL: sleep latency; WASO: wake after sleep onset; SE: sleep efficiency; REM: rapid eye movement sleep; N2, N3: stages of non-REM sleep; TST: total sleep time.

Discussion

The current study reveals altered sleep architecture in CI patients compared to HC, as well as significant differences in sleep macrostructure between CI phenotypes. Additionally, questionnaires' results revealed markedly higher scores of ISI and BDI in CI patients, with significantly more severe insomnia symptoms and depressive traits in the ISSD. The conducted correlation analysis revealed a significant positive correlation between questionnaires and objective PSG parameters.

An extensive body of research indicates that the main PSG alterations observed in CI include reduced TST, prolonged SE, decreased REM sleep duration, increased N2, and a higher frequency of microarousals.[6,7,17,18] Our findings partially correspond to available data. However, no significant differences were observed in our cohort in either the duration or proportional presence of REM sleep, as previously reported by authors.[10,11] On the one hand, this could be attributed to PSG's significant night-to-night variability; on the other hand, it should be noted that the quantitative distribution of sleep stages does not necessarily correlate with their stability or qualitative integrity.[19,20]

An increased proportion of N2 accompanied by reduced N3 is among the frequently reported macrostructural changes in CI.[7] This characteristic pattern of sleep architecture has been linked to the inability of patients to achieve deeper, restorative sleep, likely due to a lower arousal threshold, and may contribute to the subjective experience of non-restorative sleep despite preserved overall TST.[21] At the same time, some authors interpret elevated N2 levels as a compensatory manifestation of reduced sleep drive in these patients, a hypothesis consistent with the hyperarousal model.[22] It has also been proposed that increased N2 may represent compensatory "filling" of sleep, secondary to a primary impairment of deep sleep in insomnia, thereby serving as a non-specific marker of disturbed sleep.[23] Supporting this interpretation in our study is the negative correlation between increased duration in N2 and objectively measured reduction in N3 duration. Reduced slow-wave sleep in the presence of preserved TST has been associated with daytime fatigue and functional impairment, often in the absence of overt sleepiness.[24] Of particular interest is the observation that patients with acute insomnia and reduced N3 are more likely to develop CI than those with preserved N3 duration, supporting the hypothesis that disturbed sleep architecture may represent a pre-existing vulnerability factor, consistent with the predisposing component of Spielman's model.[25] Additionally, reduced slow-wave sleep may also be interpreted as a manifestation of a depressive profile. Impairments in deep sleep lead to increased fatigue, reduced cognitive performance, and mood disturbances, thereby establishing a vicious cycle between poor sleep quality and depressive symptoms.[26] Patients with depression frequently exhibit reduced duration and proportion of N3 sleep, which is associated with disrupted sleep architecture and impaired recovery.[27] Despite showing significant reduction in N3 duration and markedly increased BDI scores, no significant correlation between both parameters is present in our sample, thus warranting further investigation in future research.

Furthermore, increased WASO is a characteristic PSG feature of CI and was also observed in our study. WASO is an objective marker of sleep fragmentation, contributing to the non-restorative nature and lack of consolidated structural integrity of sleep in CI.[28] It is widely regarded as a marker of hyperarousal and reduced arousal threshold, reflecting cortical hyperactivity in patients who demonstrate increased beta power.[29] Importantly, WASO measurements do not appear to be substantially influenced by the sleep environment or by prior exposure to PSG, making it a robust objective marker of insomnia-related sleep disturbance.[30] The observed negative correlation between WASO and N3 duration in our cohort points to the fact that deep sleep is particularly vulnerable to sleep fragmentation and corresponds to the reported daytime symptoms of patients. This pattern of disrupted sleep macroarchitecture has also been reported by other authors and may be considered characteristic of CI, providing a potential explanation for the associated symptomatology.[16]

We subdivided the patient group into two subgroups according to self-reported TST into CI with subjectively reported normal (INSD) and with subjective short (ISSD) sleep duration. Comparative analysis of PSG parameters revealed significantly shorter objectively measured TST in ISSD. These findings differ from the more commonly reported discrepancy between objectively and subjectively reported sleep duration.[31] In our cohort, however, subjective sleep duration was derived from the average self-reported sleep duration over a 14-day period, thereby minimizing the influence of night-to-night variability and yielding values closely aligned with objective measurements.

The only significant difference in sleep macroarchitecture between the two subgroups was reduced REM sleep duration in ISSD. In INSD, also referred to as paradoxical insomnia, significant alterations in sleep macroarchitecture are typically absent, whereas shorter REM duration has been more frequently described in ISSD.[12] This phenomenon may contribute to impaired emotional processing, disrupted memory consolidation, and an increased risk of depressive symptomatology.[11] On the other hand, Perusse et al. did not identify significant differences in REM duration, thereby questioning the role of REM sleep as a reliable indicator of hyperarousal in CI and further underscoring the phenotypic heterogeneity of CI.[32] REM sleep instability has emerged as a useful framework for understanding SSM.[9,10] REM instability contributes to prolonged WASO and may be regarded as a potential substrate of SSM, as such instability predisposes to sleep fragmentation and renders the corresponding sleep stage more vulnerable to both internal and external arousing stimuli.[10] Given that REM sleep is crucial for emotional regulation and cognitive performance, disruption of REM structure would interfere with normal sleep consolidation and impair emotional processing, thereby affecting psychological stability and contributing to depressive symptomatology, further supporting the bidirectional link between CI and depression.[33] Although there were no significant correlations between REM duration and the other variables measured in our study, its reduction in ISSD may contribute to overestimation of wakefulness, impaired cognitive and emotional processing, and the development of depressive symptoms.

The strong positive correlation between ISI and BDI scores indicates shared characteristics in the profiles of patients with depression and CI, which underscores the similarities in the presentation and pathogenesis of these disorders. Although no causal relationships can be established, these findings highlight the interaction between mental health and sleep quality.[27] PSG evidence of disturbed sleep has been reported across nearly all psychiatric conditions – insomnia is frequently an initial symptom of several mental disorders, most notably major depressive disorder (MDD).[34,35] The relationship between CI and disorders within the anxiety–depressive spectrum and/or the affective continuum is bidirectional and multifactorial.[2].

The clinical relevance of CI for mental health is further emphasized by evidence linking shortened sleep to an increased risk of developing depressive symptoms.[36] Moreover, depressive symptoms frequently recur after clinical remission in patients with a history of CI, while insomnia complaints are associated with a threefold increased risk of MDD, particularly when coupled with objective short sleep duration.[36] A plausible mechanism explaining this relationship, based on the classical 3-P model, is that stressful life events act as precipitating factors for CI, inducing persistent alterations in sleep while simultaneously contributing to the development of depressive traits through mechanisms involving disruption of monoaminergic and serotonergic neurotransmission, thereby promoting wakefulness.[37] In our study, patients classified as ISSD on the basis of subjectively reported TST demonstrated significantly higher ISI and BDI scores, implying that even subjective phenotyping reflects meaningful differences in insomnia severity and depressive symptom burden.

The present study provides PSG confirmation of altered sleep macrostructure in CI patients and its phenotypes, based on TST. The presented results combine objective and subjective data, providing a possible foundation for phenotyping CI. However, our work has limitations that must be recognized. The relatively small sample size, especially between CI subgroups, limits the interpretability of the results and the extrapolation of data. Secondly, the cross-sectional design of the study doesn't provide a foundation for identifying causal relationships between altered sleep structures, CI profiles, and clinical differences. Additionally, insomnia phenotypes are based on subjectively reported sleep duration. Although averaged over 14 consecutive nights, data remain self-reported and cannot be considered equivalent to objective phenotyping. Finally, our data was obtained from a single night of PSG, which might not fully capture the habitual sleep of the subjects.

Conclusion

Chronic insomnia is a prevalent sleep disorder, characterized by objectively measured alterations in sleep architecture, rather than simply subjective disturbance of sleep continuity accompanied by daytime impairments. Insomnia with short sleep duration represents a more severe phenotype with greater depressive symptom burden and reduced REM sleep. These findings highlight the importance of objective measurements in CI diagnosis and its phenotypic characterization.

Ethical approval

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee of the Medical University of Plovdiv (protocol No. HO-11/2021).

Ethical statements

- The authors declared that no clinical trials were used in the present study.
- The authors declared that no experiments on humans or human tissues were performed for the present study.
- Written informed consent was obtained from all subjects involved in the study. The signed informed consent forms are safely deposited at the Department of Pathophysiology in the Medical University of Plovdiv and available for review upon request.
- The authors declared that no experiments on animals were performed for the present study.
- The authors declared that no commercially available immortalized human and animal cell lines were used in the present study.

Conflict of interest

We declare no conflict of interest between the authors of this paper and other entities.

Use of AI

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Author contributions

Both authors have contributed equally to the preparation of this manuscript and have permitted their names to be included as co-authors.

Data availability

All data used are referenced or included in the article.

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