

Frailty–Sleep Quality Profiles and Associated Factors in Older Adults Living with Type 2 Diabetes: A Latent Profile Analysis

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Abstract

Background

Frailty and poor sleep are common in older adults with type 2 diabetes mellitus, but their joint patterns may be obscured by total-score approaches. This study aimed to identify latent frailty–sleep profiles and examine factors associated with profile membership.

Methods

A convenience sample of 380 older adults with type 2 diabetes mellitus was recruited from the Department of Endocrinology and Geriatrics of a tertiary grade-A general hospital in Guangzhou, China, from June 2025 to June 2026. Participants completed a general information questionnaire, the Tilburg Frailty Indicator (TFI), and the Pittsburgh Sleep Quality Index (PSQI). Latent profile analysis was conducted using the three TFI dimensions and seven PSQI components as continuous indicators. Univariate analyses and multinomial logistic regression were used to examine factors associated with profile membership.

Results

Three latent frailty–sleep groups were identified: a relatively healthy group ($n = 191$, 50.26%), a sleep-disorder predominant group ($n = 144$, 37.89%), and a hypnotic-use and sleep-onset difficulty group ($n = 45$, 11.85%). Multinomial logistic regression showed that gender and regular exercise were associated with both higher-risk profiles. A history of falls was associated only with the sleep-disorder predominant group, whereas smoking history and polypharmacy were associated only with the hypnotic-use and sleep-onset difficulty group (all $P < 0.05$).

Conclusions

Frailty and sleep quality among older adults with type 2 diabetes mellitus showed clear heterogeneity. These findings support profile-specific screening and stratified interventions, with attention to sleep management, exercise promotion, fall prevention, smoking cessation, and medication review according to the dominant characteristics of each subgroup.

Background

With the acceleration of global population aging, diabetes mellitus has become a major chronic disease threatening the health of older adults. Frailty is a dynamic state characterized by decreased physiological reserve and increased vulnerability to adverse health outcomes. Its prevalence increases with age [1], and frailty is closely associated with hospitalization, disability, and mortality [2, 3]. Against the background of population aging, the number of people living with frailty is expected to increase substantially [4]. When type 2 diabetes mellitus coexists with frailty, patients may become more vulnerable and face a higher risk of adverse health outcomes [5].

Sleep disturbance is also common and clinically important. Sleep disturbance may affect endocrine, immune, and metabolic functions [6, 7], and evidence suggests a U-shaped association between sleep duration and diabetes risk, in which both short and long sleep duration are associated with increased diabetes risk [8]. Difficulty initiating sleep or use of hypnotic drugs has also been associated with a higher incidence of diabetes [9]. Importantly, sleep disturbance and type 2 diabetes may have a bidirectional relationship. Sleep disturbance may increase diabetes risk by affecting glucose metabolism and weight regulation [10], while diabetes-related complications, such as painful peripheral neuropathy and nocturia related to poor glycemic control, may induce or worsen sleep disturbance [11–13].

Current assessments of frailty in older adults with diabetes often rely on total scores and treat frailty as a single-dimensional construct. However, frailty encompasses physical, psychological, and social domains, and marked heterogeneity may exist between individuals. A one-size-fits-all approach may overlook distinct patterns of frailty and sleep problems, thereby reducing the precision and effectiveness of interventions. Latent profile analysis (LPA) is a model-based person-centered method that identifies homogeneous subgroups based on similar response patterns and can reveal group-specific characteristics [14]. Therefore, this study used LPA to explore latent frailty–sleep profiles among older adults with type 2 diabetes mellitus and further analyzed factors associated with membership in different profiles.

Methods

Study design and setting

This cross-sectional study used convenience sampling. Older adults with type 2 diabetes mellitus treated in the Department of Endocrinology and Geriatrics of a tertiary grade-A general hospital in Guangzhou, China, were recruited from June 2025 to June 2026. Inclusion criteria were: (1) age ≥ 60 years; (2) diagnosis of diabetes mellitus according to the Chinese guideline for the prevention and treatment of type 2 diabetes mellitus [15]; (3) clear consciousness and basic communication and comprehension ability; and (4) voluntary participation with written informed consent. Exclusion criteria were: (1) severe cognitive impairment or psychiatric disorder; (2) severe organ failure or terminal-stage tumor; and (3) incomplete data.

Sample size was estimated using the standard formula for cross-sectional studies:

$$N = Z^2 \frac{P(1-P)}{\delta^2}$$
 where $\alpha = 0.05$, Z , P represents the expected prevalence, and δ denotes the allowable margin of error. Based on previous reviews, the prevalence of frailty among patients with diabetes is approximately 30% [16]. With ($P = 0.30$) and ($\delta = 0.05$), the minimum required sample size was calculated to be 323 participants. Assuming a valid response rate of 90%, the adjusted minimum sample size was 359. A total of 400 patients were initially recruited. Of these, 12 did not meet the eligibility criteria and 8 withdrew consent. Finally, 380 participants were included in the analysis. The final analytic sample exceeded the minimum requirement, providing adequate precision for the cross-sectional estimates and ensuring transparent accounting of participant inclusion.

Measures

Instrument Design

General information questionnaire

The general information questionnaire was developed by the research team after consultation with clinical nursing experts and a review of the relevant literature. It collected demographic, lifestyle, and clinical characteristics, including age, sex, education level, marital status, living arrangement, smoking status, alcohol consumption, regular exercise, history of falls, duration of type 2 diabetes, glycated hemoglobin, comorbidities, diabetes-related complications, and medication use.

Tilburg Frailty Indicator

The Tilburg Frailty Indicator (TFI), developed by Gobbens et al. [17], was used to assess frailty in older adults. The Chinese version was introduced by Xing et al. [18]. The total score ranges from 0 to 15, with higher scores indicating more severe

frailty. The Chinese TFI used in this study has good reliability and validity, with a Cronbach alpha coefficient of 0.82.

Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI), developed by Buysse et al. [19], was used to assess sleep quality during the previous month. The Chinese version was introduced by Liu et al. [20]. The PSQI contains 18 scored items grouped into seven components; one additional item is not included in the score. Each component is scored from 0 to 3, and the total score ranges from 0 to 21. A PSQI score > 7 indicates poor sleep quality, whereas a score ≤ 7 indicates good sleep quality. The Chinese PSQI has a Cronbach alpha coefficient of 0.852.

Data Collection and Quality Control

Before data collection, trained members of the research team explained the purpose and significance of the study and provided instructions for completing the questionnaires. After written informed consent was obtained, questionnaires were distributed and completed by the participants themselves. Questionnaires were collected on site and checked immediately for omissions; missing responses were supplemented in a timely manner when possible.

Statistical analysis

Data were analyzed using SPSS 26.0 and Mplus 8.3. Categorical variables were described as frequencies and percentages. Normally distributed continuous variables were described as mean $\pm$ standard deviation, and comparisons between groups were performed using analysis of variance. Non-normally distributed variables were described as median and interquartile range and compared using non-parametric tests.

To identify latent subgroups with distinct frailty–sleep characteristics among older adults with type 2 diabetes mellitus, joint latent profile analysis was performed. The three TFI dimensions (physical, psychological, and social frailty) and seven PSQI components (subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, hypnotic drug use, and daytime dysfunction) were used as 10 continuous manifest indicators. The raw dimension scores were used in the primary LPA to preserve clinical interpretability. Because the PSQI components and TFI dimensions had different possible score ranges, a sensitivity analysis was conducted using standardized indicators. Each of the 10 manifest indicators was transformed into a z score before refitting the latent profile models. Models with one to six latent profiles were fitted in Mplus 8.3. To improve the likelihood of convergence to a global optimum, 5000 random starts were specified, with the best 1000 solutions retained. Model fit was evaluated using log likelihood, Akaike information criterion (AIC), Bayesian information criterion (BIC), sample-size adjusted BIC (aBIC), entropy, Lo-Mendell-Rubin adjusted likelihood ratio test (LMRT), and bootstrap likelihood ratio test (BLRT). Lower AIC, BIC, and aBIC values indicated better model fit; entropy closer to 1 indicated better classification accuracy; and $P < 0.05$ for LMRT or BLRT indicated that the k-profile model fit significantly better than the k-1 profile model. Analysis of variance, chi-square test, Fisher exact test, Kruskal-Wallis H test, and multinomial logistic regression were conducted using SPSS 26.0. The significance level was set at $\alpha = 0.05$.

Ethics

The study was approved by the Ethics Committee of the Third Affiliated Hospital of Guangzhou Medical University (Approval No. YL-20260727000576). All participants provided written informed consent before participation. The analysis used de-identified data and was conducted in accordance with the Declaration of Helsinki.

Use of generative AI and AI-assisted technologies

During manuscript preparation, the authors used OpenAI ChatGPT to improve language readability and adapt the manuscript formatting to the target journal. The authors subsequently reviewed and edited the output and take full

responsibility for the content of the manuscript.

Results

Participant characteristics

A total of 380 older adults with type 2 diabetes mellitus were included. Among them, 174 were male (45.8%) and 206 were female (54.2%). Regarding marital status, 275 participants were married (72.4%), and 105 were unmarried, divorced, or widowed (27.6%). Forty-five participants lived alone (11.8%), whereas 335 did not live alone (88.2%). The mean age was 71.09 years. Detailed demographic and clinical characteristics are shown in Table 2.

Table 2

Univariate analyses of factors associated with joint frailty–sleep profiles in older adults with type 2 diabetes mellitus ($n = 380$)

Variables	Groups	C1 Sleep-disorder predominant ($n = 144$)	C2 Relatively healthy ($n = 191$)	C3 Hypnotic- use and sleep- onset difficulty ($n = 45$)	χ^2/H	P value
Age[n,%]	60 ~ 69years old	48(33.3)	98(51.3)	12(26.7)	23.321	0.001
	70 ~ 79years old	62(43.1)	75(39.3)	20(44.4)		
	≥ 80 years old	34(23.6)	18(9.4)	13(28.9)		
Gender[n,%]	Female	93 (64.6)	81 (42.4)	32 (71.1)	22.138	0.001
	Male	51 (35.4)	110 (57.6)	13 (28.9)		
Marital Status,[n,%]	Married	95 (66.0)	155 (81.2)	25 (55.6)	16.676	0.001
	Unmarried/divorced/widowed	49 (34.0)	36 (18.8)	20 (44.4)		
Education Level [n,%]	Primary school and below	57(39.6)	48(25.1)	15(33.3)	13.706	0.033
	Junior high school	41(28.5)	52(27.2)	16(35.6)		
	High school/technical school	36(25.0)	66(34.6)	12(26.7)		
	College and above	10(6.9)	25(13.1)	2(4.4)		
Living Arrangement[n,%]	Not living alone	122(84.7)	177(92.7)	36(80.0)	8.222	0.016
	Living alone	22(15.3)	14(7.3)	9(20.0)		
Payment method[n,%]	Out of pocket	11(7.6)	8(4.2)	0(0.0)	6.214	0.184
	Medical insurance	123(85.4)	163(85.3)	42(93.3)		
	Other	10(6.9)	20(10.5)	3(6.7)		
BMI (kg/m ²)	<18.5	7(4.9)	8(4.2)	3(6.7)	4.789	0.571
	18.5 ~ 23.9	66(45.8)	98(51.3)	27(60.0)		
	24.0 ~ 27.9	52(36.1)	62(32.5)	9(20.0)		
	≥ 28	19(13.2)	23(12.0)	6(13.3)		
Waist circumference(cm)		88.58	88.40	88.28	90.108	0.936
Regular exercise[n,%]	Yes	69(47.9)	158(82.7)	19(42.2)	54.904	0.001
	No	75(52.1)	33(17.3)	26(57.8)		
Alcohol consumption history[n,%]	Never	106(73.6)	127(66.5)	36(80.0)	4.308	0.366

Variables	Groups	C1 Sleep-disorder predominant (n = 144)	C2 Relatively healthy (n = 191)	C3 Hypnotic- use and sleep- onset difficulty (n = 45)	χ^2/H	P value
	Current drinking	14(9.7)	26(13.6)	4(8.9)		
	Former drinking	24(16.7)	38(19.9)	5(11.1)		
Smoking history[n,%]	Never	102(70.8)	110(57.6)	31(68.9)	9.682	0.046
	Current smoking	19(13.2)	43(22.5)	4(8.9)		
	Former smoking	23(16.0)	38(19.9)	10(22.2)		
History of falls[n,%]	No history of falls	106(73.6)	171(89.5)	41(91.1)	17.298	0.001
	History of falls	38(26.4)	20(10.5)	4(8.9)		
Hypoglycemic episodes per year[n,%]	0	101(70.1)	143(74.9)	29(64.4)	2.703	0.609
	1–3	27(18.8)	29(15.2)	11(24.4)		
	4–12	16(11.1)	19(9.9)	5(11.1)		
Duration of diabetes diagnosis[n,%]	< 1 year	9(6.3)	19(9.9)	1(2.2)	15.493	0.017
	1 to 10 years	36(25.0)	66(34.6)	11(24.4)		
	10 to 20 years	44(30.6)	65(34.0)	17(37.8)		
	> 20 years	55(38.2)	41(21.5)	16(35.6)		
Number of diabetes complications[n,%]	1–2 diseases	86(59.7)	157(82.2)	28(62.2)	22.340	0.001
	>=3 diseases	58(40.3)	34(17.8)	17(37.8)		
Presence of comorbidities[n,%]	Yes	124(86.1)	135(70.7)	42(93.3)		0.001
	No	20(13.9)	56(29.3)	3(6.7)		
Polypharmacy [n,%]	Yes	104(72.2)	108(56.5)	41(91.1)	22.875	0.001
	No	40(27.8)	83(43.5)	4(8.9)		
Glucose-lowering regimen[n,%]	None	2(1.4)	3(1.6)	0(0)	9.342	0.155
	Oral	52(36.1)	73(38.2)	21(46.7)		
	Insulin	0(0)	7(3.7)	0(0)		
	Oral + insulin	90(62.5)	108(56.5)	24(53.3)		

Variables	Groups	C1 Sleep-disorder predominant (<i>n</i> = 144)	C2 Relatively healthy (<i>n</i> = 191)	C3 Hypnotic- use and sleep- onset difficulty (<i>n</i> = 45)	χ^2/H	P value
Hemoglobin, g/L (P25, P75)		129.50(115.25, 139.75)	132(121.0, 143.0)	124(107.0, 138.0)	8.268	0.016
HbA1c (P25, P75)		8.30(7.1, 10.3)	8.75(7.2, 10.65)	7.60(6.7, 9.05)	7.484	0.024

Latent profile analysis

In this study, six latent profiles were fitted, and the three-profile model was selected as the optimal solution. The values of the fit indices are shown in Table 1. When the number of profiles increased from one to three, AIC, BIC, and aBIC decreased continuously, and both LMRT and BLRT were statistically significant (all $P < 0.01$). When the number of profiles increased from three to four, AIC, BIC, and aBIC continued to decrease, but the LMRT was not significant ($P = 0.407$), and the four-profile model included a small class accounting for only 4.8% of the sample. When the number of profiles increased from four to five, the LMRT also was not significant ($P = 0.751$), and an extremely small group accounting for only 2.1% of the sample appeared. Considering model fit, profile stability, and clinical interpretability, the three-profile model was selected as the optimal model. The sensitivity analysis using standardized indicators yielded a similar three-profile solution. Although the numerical order of the classes was rearranged by Mplus, the profiles remained clinically interpretable as a relatively healthy group, a sleep-disorder predominant group, and a hypnotic-use and sleep-onset difficulty group. The indicator patterns of the three latent frailty–sleep profiles are presented in Fig. 1.

Table 1
Fit indices for the latent profile models

Number of profiles	AIC	BIC	aBIC	Entropy	LMRT	BLRT	Class probability
1	9852.564	9931.367	9867.911				
2	8830.466	8952.611	8854.254	0.910	< 0.001	< 0.001	0.52757/0.47243
3	7991.820	8157.308	8024.050	0.940	0.0029	< 0.001	0.37905/ 0.50253/ 0.11842
4	7658.487	7867.316	7699.158	0.957	0.407	< 0.001	0.48850/ 0.09211/ 0.36939/ 0.05000
5	7217.515	7469.686	7266.626	0.969	0.7513	< 0.001	0.47614/ 0.09737/ 0.08947/ 0.31596/ 0.02105
6	7084.381	7379.894	7141.934	0.973	1.000	< 0.001	0.47895/ 0.08947/ 0.07632/ 0.02105/ 0.02105/0.31316
Note: AIC stands for Akaike information criterion, BIC stands for Bayesian information criterion, aBIC, stands for Adjusted Bayesian Information Criterion, Entropy refers to Information Entropy, LMRT refers to the Lo-Mendell-Rubin adjusted likelihood ratio test, and BLRT refers to the Bootstrap likelihood ratio test.							

[Insert Fig. 1 here]

Univariate analyses

Univariate analysis showed no significant differences between profiles in payment method for medical expenses, body mass index, waist circumference, hypoglycemic episodes, glucose-lowering regimen, or alcohol consumption history ($P > 0.05$). However, age, gender, marital status, education level, living arrangement, regular exercise, smoking history, history of falls, duration of diabetes, number of diabetes complications, presence of comorbidities, HbA1c, and hemoglobin differed significantly among the profiles ($P < 0.05$), as shown in Table 2.

Multinomial logistic regression

The three frailty–sleep profiles identified by LPA were used as the dependent variable, with the relatively healthy group as the reference category. Variables that were significant in univariate analyses ($P < 0.05$) were used as independent variables. HbA1c and hemoglobin were included as covariates. Assignment methods for independent variables are shown in Table 3. Multinomial logistic regression showed that gender and regular exercise were associated with both higher-risk profiles. A history of falls was associated only with the sleep-disorder predominant group, whereas smoking history and polypharmacy were associated only with the hypnotic-use and sleep-onset difficulty group (all $P < 0.05$), as shown in Table 4.

Table 3
Coding of independent variables

Variable	Assignment method
1. Gender	Male = 1; female = 2
2. Marital status	Married = 1; unmarried/divorced/widowed = 2
3. Education level	Primary school and below = 1; junior high school = 2; high school/technical school = 3; college and above = 4
4. Living arrangement	Not living alone = 0; living alone = 1
5. Regular exercise	No = 0; yes = 1
6. History of falls	No history of falls = 0; History of falls = 1
7. Smoking history	Never = 0; current smoking = 1; former smoking = 2
8. Diabetes duration	< 1 year = 1; 1–10 years = 2; 10–20 years = 3; ≥20 years = 4
9. Number of diabetes complications	1–2 diseases = 1; ≥3 diseases = 2
10. Comorbidities	No = 0; yes = 1
11. Polypharmacy	No = 0; yes = 1

Table 4
Multinomial logistic regression of factors associated with frailty–sleep profile membership

Independent variable	Beta	SE	Wald χ^2	P value	OR	95% CI
Sleep-disorder predominant vs relatively healthy						
Constant	-0.014	1.340	0.00	0.992		
Hemoglobin	0.014	0.008	3.087	0.079	1.014	[0.998,1.029]
Male (reference: female)	-0.925	0.427	4.701	0.030	0.397	[0.172,0.915]
Married (reference: unmarried/divorced/widowed)	-0.071	0.366	0.037	0.847	0.932	[0.455,1.910]
Not living alone (reference: living alone)	-0.363	0.500	0.528	0.467	0.695	[0.261,1.852]
No regular exercise (reference: yes)	1.284	0.311	17.057	0.001	3.613	[1.964,6.646]
No history of falls (reference: History of falls)	-1.048	0.341	9.427	0.002	0.350	[0.179,0.684]
Hypnotic-use and sleep-onset difficulty vs relatively healthy						
Constant	2.237	2.163	1.070	0.301		
Male (reference: female)	-2.744	0.989	7.700	0.006	0.064	[0.009,0.447]
No regular exercise (reference: yes)	1.334	0.443	9.057	0.003	3.798	[1.593,9.056]
Never smoking (reference: former smoking)	-2.397	1.032	5.399	0.020	0.091	[0.012,0.687]
1–2 diabetes complications (reference: ≥ 3 diseases)	0.212	0.458	0.214	0.644	1.236	[0.504,3.034]
No polypharmacy (reference: yes)	-1.540	0.701	4.820	0.028	0.214	[0.054,0.848]
Notes: The relatively healthy profile was used as the reference outcome category.						
Abbreviations: β , regression coefficient; SE, standard error; Wald χ^2 , Wald chi-square statistic; OR, odds ratio; CI, confidence interval.						
Notes: C1- Sleep-Disorder Predominant Group (n = 144, 37.89%), C2- Relatively Healthy Group (n = 191, 50.26%), C3- Hypnotic-use and sleep-onset difficulty Group (n = 45, 11.85%). A sensitivity analysis using standardized indicators showed a similar three-profile pattern.						

Discussion

Overall frailty

In this study, the mean frailty score of 380 older adults with type 2 diabetes mellitus was 3.79. Among the frailty dimensions, physical frailty had the highest score, suggesting that decline in physical function was the main manifestation of frailty in this population. This finding is consistent with previous evidence and may be related to diabetes-associated sarcopenia, neuropathy, tissue damage caused by long-term hyperglycemia, and reduced mobility [21]. Physical frailty may serve as an early manifestation of frailty and should be a focus of early clinical identification and intervention.

Overall sleep quality

Regarding sleep quality, the mean PSQI score was 9.09, and 270 participants (71.1%) had poor sleep quality according to the PSQI cut-off of > 7 , indicating that more than half of the sample had significant sleep problems. This prevalence is similar to findings from related studies, suggesting that sleep problems are common among older adults with type 2 diabetes mellitus [22–24]. Sleep disturbance and type 2 diabetes mellitus may reinforce each other in a vicious cycle. Sleep disturbance may promote diabetes progression through central mechanisms, including decreased cerebral glucose utilization, altered orexin responses, and hyperactivation of the hypothalamic-pituitary-adrenal axis [25], as well as behavioral mechanisms, including poor self-care and unhealthy lifestyle behaviors [26, 27]. Diabetes and its comorbidities, including obesity, nocturnal hypoglycemia, sympathetic activation, neuropathic pain, and nocturia, may also induce or exacerbate sleep disturbance [28]. In addition, medication-related factors may also contribute to sleep problems. Previous reviews have shown that various psychotropic and non-psychotropic medications can induce insomnia or excessive sleepiness, and commonly used drugs such as glucocorticoids, statins, sedative-hypnotics, and some glucose-lowering agents may influence sleep quality through different mechanisms [29]. In the PSQI dimensions, daytime dysfunction had the highest score, indicating that sleep problems substantially affected daytime energy, attention, and daily functioning. Daytime dysfunction may overlap with fatigue and cognitive decline in patients with diabetes and further weaken self-management capacity, creating a vicious cycle of poor sleep, reduced daytime functioning, and poor glycemic control.

Three latent frailty–sleep profiles

This study identified three distinct frailty–sleep profiles: the relatively healthy group, the sleep-disorder predominant group, and the hypnotic-use and sleep-onset difficulty group. The relatively healthy group accounted for 50.26% of the sample and showed the lowest scores across all 10 dimensions. This finding suggests that more than half of older adults with diabetes still maintained relatively good sleep quality and low frailty levels. For this group, the priority should be health education, preventive measures, maintenance of existing healthy behaviors, and regular monitoring to prevent transition to higher-risk profiles.

The sleep-disorder predominant group accounted for 37.89% of the sample. Its core characteristics were comprehensive sleep problems, including prolonged sleep latency, reduced sleep efficiency, and daytime dysfunction, together with prominent physical frailty, but very low use of hypnotic drugs. This group indicates that many patients may suffer from substantial insomnia-related difficulties without seeking or relying on pharmacologic intervention, while still retaining relatively preserved psychosocial resources. Clinicians should proactively screen for sleep problems in this group and provide non-pharmacologic interventions such as cognitive behavioral therapy for insomnia and exercise therapy to prevent further deterioration in physical function.

The hypnotic-use and sleep-onset difficulty group accounted for 11.85% of the sample and was the most clinically distinctive group. Its most prominent feature was near-maximal hypnotic drug use, along with the highest scores for subjective sleep quality and sleep latency. However, impairment in sleep duration and sleep efficiency was lower than that in the sleep-disorder predominant group. This contradictory pattern of high medication use, high subjective distress, and relatively preserved sleep duration suggests that these patients relied heavily on hypnotic drugs, but medication did not adequately improve their subjective sleep experience. The core problem appeared to be difficulty falling asleep rather than sleep maintenance. The identification of this group adds to existing evidence because previous studies have tended to focus on frailty or sleep as isolated dimensions and rarely considered medication dependence as an independent phenotype.

The robustness of the three-profile solution was supported by the sensitivity analysis based on standardized indicators. This suggests that the identified profiles were not merely driven by differences in the score ranges of the PSQI components and TFI dimensions.

Factors associated with profile membership

Gender was associated with both higher-risk profiles. Compared with men, women had higher odds of belonging to the sleep-disorder predominant group and especially the hypnotic-use and sleep-onset difficulty group. This finding suggests that clinicians should not only assess frailty and sleep problems in older women with diabetes but also remain alert to the risk of hypnotic medication dependence. Potential mechanisms may include decreased estrogen levels after menopause, higher prevalence of anxiety and depression, and greater psychosocial stress [30]. Evidence also suggests that chronic insufficient sleep can reduce insulin sensitivity in women, and optimizing sleep may be important for cardiometabolic prevention during the menopausal transition [31].

Regular exercise was associated with lower odds of membership in both higher-risk profiles. Compared with the relatively healthy group, participants without regular exercise were more likely to belong to both the sleep-disorder predominant group and the hypnotic-use and sleep-onset difficulty group. This finding suggests that exercise may be a foundational intervention for all groups and may be particularly beneficial for patients with medication-related sleep problems. The mechanism may involve improvement in anxiety and depressive symptoms, which are important drivers of hypnotic drug use. Previous studies have shown that exercise can improve physical function among frail older adults, including muscle strength, gait speed, balance, mobility, and physical performance [32], and may also improve cognitive function [33]. Physical activity may also buffer the adverse association between sedentary time and frailty [34].

A history of falls was associated only with the sleep-disorder predominant group. This group was characterized by prominent physical frailty and daytime dysfunction, both of which may increase fall risk and make recovery after a fall more difficult, forming a cycle of sleep disturbance, falls, and functional decline. Frailty has been associated with increased fall risk, and falls are an important reason for hospitalization among frail patients [35]. For this group, clinical intervention should integrate sleep management with fall-prevention strategies, such as environmental modification, balance training, and assistive device use.

Smoking history and polypharmacy were associated only with the hypnotic-use and sleep-onset difficulty group. This finding highlights two group-specific risk factors. Smoking may interfere with sleep architecture through nicotine-related stimulation of neurotransmitter release, which may encourage patients to seek pharmacologic sleep assistance [36]. Polypharmacy may reflect a heavier comorbidity burden and may increase the risk of drug interactions and hypnotic medication use or dependence [37]. These specific associations suggest that intervention for the hypnotic-use and sleep-onset difficulty group should emphasize smoking cessation and medication review rather than general sleep health education alone.

Clinical implications

The identification of heterogeneous frailty–sleep groups supports the use of stratified management in older adults with type 2 diabetes mellitus. The relatively healthy group may benefit from routine monitoring and preventive education; the sleep-disorder predominant group requires active sleep screening, non-pharmacologic sleep interventions, physical function support, and fall prevention; and the hypnotic-use and sleep-onset difficulty group requires careful assessment of hypnotic medication use, sleep-onset difficulties, smoking status, and polypharmacy. Such profile-specific interventions may improve precision in geriatric diabetes care.

Limitations

Several limitations should be acknowledged. First, this was a single-center cross-sectional study using convenience sampling, which limits causal inference and may reduce generalizability. Second, sleep quality and some clinical characteristics were assessed using self-report instruments, which may introduce recall bias. Third, no objective sleep measures, such as actigraphy or polysomnography, were included. Fourth, although the LPA model showed good classification accuracy, the identified profiles require validation in external samples and longitudinal studies. Future

research should examine whether profile-specific interventions can improve frailty, sleep quality, and diabetes-related outcomes.

Conclusions

This study revealed marked heterogeneity in the joint frailty–sleep phenotype among older adults with type 2 diabetes mellitus, identifying three distinct groups: a relatively healthy group, a sleep-disorder predominant group, and a hypnotic-use and sleep-onset difficulty group. Sex, regular physical activity, history of falls, smoking history, and polypharmacy differentiated these profiles, with the strength of each association varying by subtype. These findings indicate that clinical management should be stratified according to subtype-specific characteristics to enable more precise and targeted intervention.

Abbreviations

aBIC
sample-size adjusted Bayesian information criterion
AIC
Akaike information criterion
BIC
Bayesian information criterion
BLRT
bootstrap likelihood ratio test
BMI
body mass index
CI
confidence interval
HbA1c
glycated hemoglobin
LPA
latent profile analysis
LMRT
Lo-Mendell-Rubin adjusted likelihood ratio test
OR
odds ratio
PSQI
Pittsburgh Sleep Quality Index
TFI
Tilburg Frailty Indicator.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Third Affiliated Hospital of Guangzhou Medical University (Approval No. YL-20260727000576). All participants provided written informed consent before participation.

Consent for publication

Not applicable. This manuscript does not contain identifiable individual participant data.

Author Contribution

WC and JL contributed equally to this work. WC and JL were responsible for study conception and design, data collection, data analysis, interpretation of results, and drafting of the manuscript. XX, XL, ZL, and QZ contributed to participant recruitment, data collection, data checking, and manuscript revision. XZ supervised the study, contributed to study design, provided methodological guidance, critically revised the manuscript, and approved the final version. All authors read and approved the final manuscript.

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Authors' information

Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available because they contain potentially sensitive clinical and questionnaire information, but are available from the corresponding author on reasonable request. Competing interests

The authors declare that they have no competing interests.

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Figures

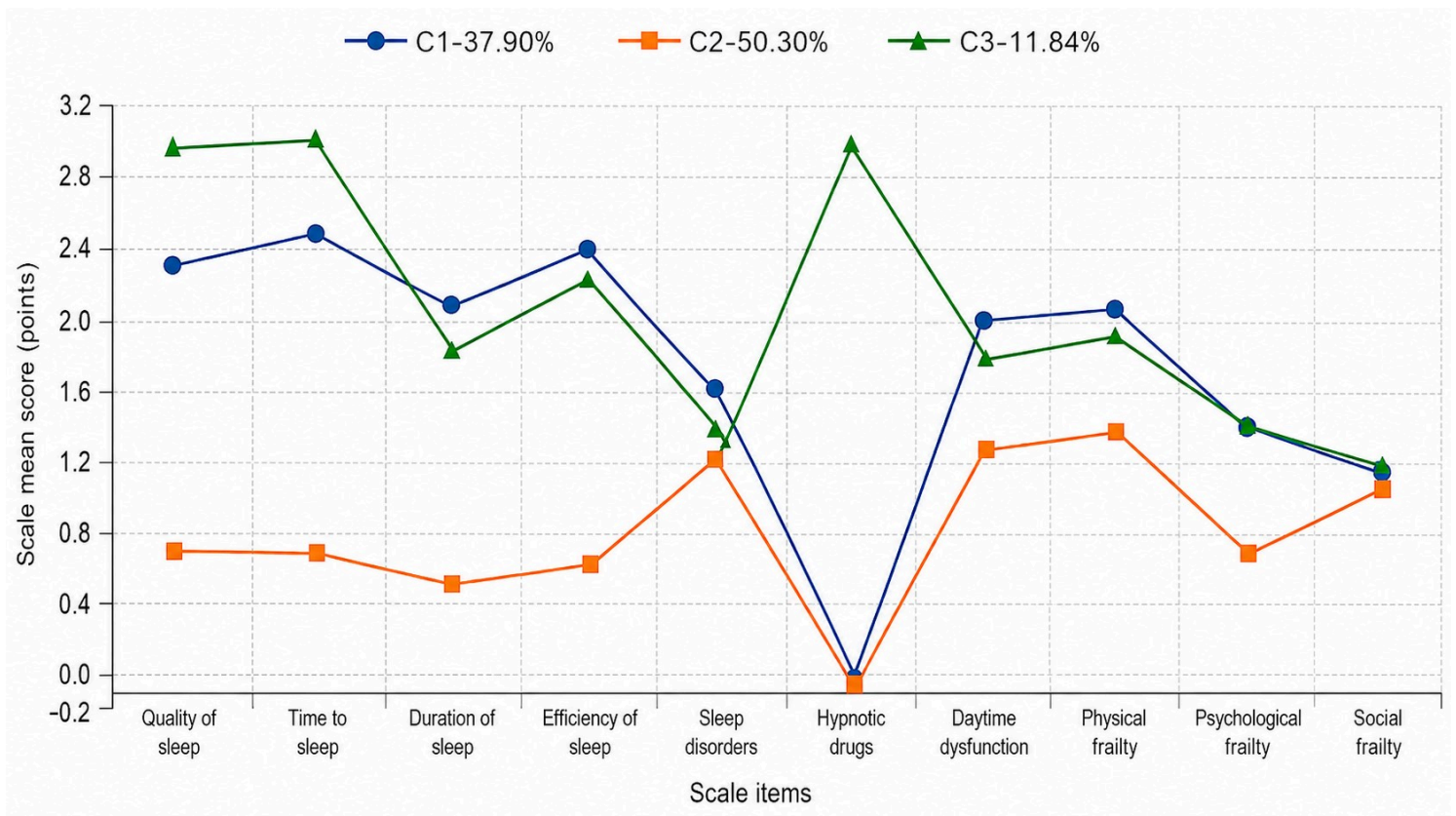


Figure 1

Joint frailty–sleep profiles in older adults with type 2 diabetes.

Notes: C1- Sleep-Disorder Predominant Group (n=144, 37.89%), C2- Relatively Healthy Group (n=191, 50.26%), C3- Hypnotic-use and sleep-onset difficulty Group (n=45, 11.85%). A sensitivity analysis using standardized indicators showed a similar three-profile pattern.