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Original Article

Association of Chronotype, Sleep Quality, Body Mass Index, and Glycemic Control in Type 2 Diabetes: A Cross-Sectional Study

Eiman Muneer Humood[1], Mousa Numan Ahmad[*2], Nahla Mousa Khawaja[1], Yousef Saleh Khader[3], Kamel Mohammad Ajlouni[1]

[1]The National Center for Diabetes, Endocrinology, and Genetics, The University of Jordan, Amman 11942, Jordan
[2]Department of Nutrition and Food Technology, Human Nutrition and Dietetics, The University of Jordan, Amman 11942, Jordan
[3]Department of Public Health and Community Medicine, Jordan University of Science and Technology, Irbid 22110, Jordan

Corresponding Author's Email: mosnuman@ju.edu.jo

Abstract

Background: Circadian misalignment via chronotype and sleep disturbances may harm metabolic control in type 2 diabetes (T2D), but evidence is unclear. **Objectives**. This study investigated the association of chronotype, sleep quality, BMI, and HbA1c in patients with T2D, with sex-specific analysis. **Methods:** This cross-sectional study included a systematic random sample of 1,000 patients with T2D, of whom 39% were male. Participants' chronotypes and sleep patterns were assessed using the reduced Morningness-Eveningness Questionnaire and the shortened Pittsburgh Sleep Quality Index (shortPSQI). Clinical data collected included BMI, HbA1c, and comorbidities. Chi-square, t-test, and regression analysis were conducted. **Results:** Participants' mean age: 60.0±11.3 years; BMI: 30.5±5.5 kg/m²; HbA1c: 7.3±1.7%. Evening chronotypes had higher BMI (p<0.001) and HbA1c >7%. In both sexes, chronotype correlated with BMI and HbA1c (p<0.05). Poor sleep (shortPSQI>4) was prevalent in 68% of participants with T2D. Being overweight (OR=1.686) and having uncontrolled HbA1c (≥7%) (OR=1.747) were independently associated with higher odds of poor sleep quality. Evening chronotypes were independently associated with both poorer glycemic control (OR=2.174) and sleep quality (OR=2.213). Female sex was independently associated with lower odds of elevated HbA1c (OR=0.605), whereas village residence (OR=1.685), insulin-based therapy (OR=4.655), combined therapy (OR=12.973), longer diabetes duration (≥10 years) (OR=2.739), poor sleep quality (OR=1.418), and non-morning chronotypes (moderately morning: OR=2.564, intermediate: OR=2.033, and moderately evening: OR=3.727) were associated with elevated HbA1c higher odds. **Conclusions:** In adults with T2D, evening chronotypes tend to have higher BMIs and HbA1c levels, especially in males, and poor sleep quality is particularly linked to these variables in females. Given the cross-sectional study design, these findings warrant further investigation in longitudinal studies.

Keywords: *Body Mass Index; Circadian Rhythm; Chronotype; Type 2 Diabetes, Sleep Quality*

Introduction

The prevalence of type 2 diabetes mellitus (T2D) has significantly increased worldwide in recent years (Mirahmadizadeh *et al.,* 2020). By 2025, almost 75% of diabetic patients worldwide are predicted to exist in developing countries (Ogurtsova *et al*., 2017; Ahmad *et al.,* 2020). T2D accounts for 90–95% of all diabetes cases (American Diabetes Association Professional Practice Committee for Diabetes, 2026), with most affected individuals being obese (Ma & Tong, 2024; Obeidat *et al.,* 2025).

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Over the past few years, chronobiology has generated significant information on obesity, metabolic syndrome, and risk factors for developing T2D (Mason *et al.,* 2020). Modern societies have abandoned sleep and eating cycles, a condition known as chrono-disruption. This practice may have detrimental consequences on health, including a high risk of chronic diseases like T2D (Mason *et al.,* 2020). Healthy adults with evening chronotypes tend to have poor sleep quality and are at high risk for metabolic disorders (Lekhwani & Das 2024). Research suggests that disrupting the body's natural circadian rhythm, such as through night shift work, may negatively affect glucose metabolism in healthy adults (Centofanti *et al.,* 2025). A longitudinal cohort study of young adults with youth-onset T2D found that the loss of glycemic control was independently associated with late bedtimes on work or school days (Koren *et al.,* 2024). Another study revealed that over three-quarters of individuals with T2D experience poor sleep quality, which is linked to poor glycemic control (Rodrigues & Safeekh, 2023).

Despite the growing body of research, findings on the relationship between chronotype, sleep quality, and metabolic health remain inconsistent (Farooque *et al.,* 2020; Strojny *et al*., 2021; Al Nefaie *et al*., 2022; Koren *et al.,* 2024; Nunez *et al.,* 2024). A study indicated that chronotype may not significantly influence glycemic outcomes (Nunez *et al.,* 2024). Nonetheless, the chronotype of obese individuals appears to have a minimal influence on their weight loss outcomes (Strojny *et al*., 2021). Some research has found no significant correlation between sleep quality and glycemic control in patients with T2D (Strojny *et al*., 2021; Al Nefaie *et al*., 2022). Moreover, the results of a cross-sectional study on patients with T2D showed that self-reported short sleep duration, daytime sleepiness, and sleep quality did not associate with diabetes complications (Koren *et al.,* 2024). Recent reports have increasingly recognized that behavioral and circadian factors are independent, modifiable predictors of poor metabolic health in T2D, even though the exact reasons for this connection remain a subject of active research (Hong *et al*., 2025; Zhu & Mi, 2025; Siddaraju *et al.,* 2026; Xu *et al.,* 2026). In essence, little is known about chronotype variations in patients with T2D and sleep quality and the potential associations with glycemic control, especially when considering multiple factors that influence the body's circadian rhythm, such as body weight status, sociodemographic attributes, sex, and diabetes duration and complications. Therefore, this study aimed to investigate the relationship between chronotype, sleep quality, body mass index, and glycemic control in patients with T2D, highlighting sex-specific patterns.

Material and Methods

Ethical Considerations

The study was approved by the Ethics Committee at the National Center for Diabetes, Endocrinology, and Genetics (No. 129/6 January 2025), Amman, Jordan, and performed in accordance with the recommendations contained in the Declaration of Helsinki (World Medical Association, 2025). Informed consent was obtained from each participant. All data were treated with strict confidentiality and used only for scientific purposes.

Study Design and Sampling

This cross-sectional study included a systematic random sample of 1,000 Jordanian adults with type 2 diabetes, aged 18 years and older, 39% of whom were male. Using a systematic random sampling design (Elfil & Negida, 2017), one in five eligible participants was selected from the endocrinology clinic at the National Center for Diabetes, Endocrinology, and Genetics (NCDEG) in Amman, Jordan. Each participant had been diagnosed with type 2 diabetes and was attending routine follow-up care appointments at the centre. Exclusion criteria included pregnancy, breastfeeding, type 1 diabetes, gestational diabetes, serious illness, or the presence of cognitive or physical disabilities. Participants were recruited consecutively during routine visits to the NCDEG, Jordan. Eligible participants met the predefined inclusion criteria and voluntarily agreed to participate. Because recruitment was conducted in a specialized diabetes centre, caution should be exercised when generalizing the findings to all individuals with T2D in Jordan.

Data Collection

Data collection was carried out through a combination of in-person interviews, a structured questionnaire, and medical record reviews. We conducted face-to-face sessions with each participant, which took approximately 10 minutes. On the day of the interview, information extracted from medical records corresponding to the previous visit (within 2 months of the interview) comprised anthropometric measures such as weight, height, and body mass index (BMI), and clinical and laboratory values, including glycated hemoglobin (HbA1c). The methods and procedures for BMI and HbA1c determination were described elsewhere (Ajlouni *et al*., 2020). The questionnaire administered to each participant gathered socio-demographic data, including age, sex, marital status, occupation, educational level, and duration of diabetes. Sleep quality was assessed using the validated Arabic version of the short PSQI (Barakat *et al.,* 2019). The shortPSQI, which comprises 13 items, has shown strong correlation with the original 19-item version and effectively assesses sleep latency, duration, efficiency, disturbances, and daytime dysfunction (Famodu *et al.,* 2018, Barakat *et al., 2018,* 20shortened Pittsburgh Sleep Quality Index 19). Higher global scores indicate poorer sleep quality. Consistent with previous validation studies, a shortPSQI score >4 was used to identify poor sleep quality and a shortPSQI score ≤ 4 to indicate good sleep quality. These thresholds have demonstrated acceptable sensitivity and specificity for detecting clinically relevant sleep quality and have been used in studies involving Arabic-speaking populations (Famodu *et al.,* 2018; Barakat *et al.,* 2019; Al Maqbali *et al.,* 2020). Chronotype was assessed using the validated Arabic version of the reduced Horne–Östberg Morningness-Eveningness Questionnaire (rMEQ) (Chaaya *et al.,* 2025). The questionnaire consists of five items with total scores ranging from 4 to 25. Participants were classified as definitely morning type (22-25), moderately morning type (18-21), intermediate type (12-17), moderately evening type (8-11), and definitely evening type (4-7). These classifications were applied consistently throughout all analyses and tables. The rMEQ has demonstrated strong reliability and validity in previous studies, with sensitivity and specificity values ranging from 83.3% to 92.7% for morning types and from 86.3% to 87.3% for evening types (Chaaya *et al.,* 2025). A pilot trial was conducted with 15 participants over two weeks to evaluate the internal consistency of the rMEQ and shortPSQI tools before commencing the main data collection. The Cronbach's alpha coefficient was calculated as 0.74, indicating acceptable internal consistency and reliability of the tools (Lopez, 2025).

Statistical Analyses

Statistical analysis was conducted using IBM SPSS Statistics version 25. Initially, the data were examined for accuracy and completeness, and any necessary corrections were made before proceeding with the analysis. Descriptive statistics were employed to summarize the data, reporting continuous variables as means and standard deviations, while categorical variables were presented as frequencies and percentages. Two multivariable binary logistic regression models were constructed. The first model examined factors associated with poor sleep quality (shortPSQI>4), whereas the second model evaluated factors associated with elevated HbA1c (≥7%). Independent variables were selected based on clinical relevance and bivariate significance (p<0.10). Categorical variables were dummy-coded, with the most prevalent or clinically 'healthy' group as the reference. Reference categories for all categorical variables are presented in Tables 4 and 5. Multicollinearity was evaluated using Variance Inflation Factors (VIF<5), and the model fit was assessed with the Hosmer–Lemeshow test. Model assumptions and multicollinearity were assessed before analysis. Odds ratios (ORs) and corresponding 95% confidence intervals (CIs) were reported. Statistical significance was established at p< 0.05. All 1,000 participants had complete data for the primary variables of interest.

Results

Characteristics of the Study Group

This study examined the sociodemographic and anthropometric characteristics (Table 1a) and the clinical, chronotype, and sleep quality attributes (Table 1b) of 1,000 participants with T2D and

identified significant sex differences. A greater proportion of females (87%) resided in urban areas compared to males (81%) (p<0.007). Regarding marital status, 20% of females were divorced or widowed versus 6% of males (p<0.001). Educationally, 25% of females had less than a high school education compared to 6% of males (p<0.001). In employment, 36% of males were employed and 60% retired, while 54% of females were in the workforce (p<0.001). Income data revealed 21% of females earned below JD 250 compared to 10% of males (p<0.001). The family history of diabetes was more prevalent in males (66%) compared to females (59%) (p<0.016). In terms of BMI, more males (43%) were overweight, while more females (53%) were obese (p<0.001). Additionally, 55% of females had been diagnosed with diabetes for fewer than 10 years compared to 47% of males (p=0.016). Female diabetes management was better (57%) than that of males (44%) (p<0.001). Nephropathy was more prevalent in males (21%) than in females (12%) (p<0.001), and cardiovascular disease also affected a higher percentage of males (26%) compared to females (19%) (p<0.003). Sleep quality showed no significant sex differences (p<0.576), although more males identified as "definitely morning type" (14%) compared to females (10%) (p<0.001).

Table 1a: *Socio-Demographic and Anthropometric Characteristics of the Study Group (n=1000)*

Variable	Total No. (%) (n=1000)	Males No. (%) (n=390)	Females No. (%) (n=610)	*p*-value*
Place of Living				
City	847 (85%)	316 (81%)	531 (87%)	<0.007
Village	154 (15%)	74 (19%)	80 (13%)	
Marital Status				
Single	42 (4%)	9 (2%)	33 (5%)	<0.001
Married	817 (82%)	359 (92%)	458 (75%)	
Divorced/Widow	142 (14%)	22 (6%)	120 (20%)	
Education				
< High School	176 (18%)	23 (6%)	153 (25%)	<0.001
High School	202 (20%)	68 (17%)	134 (22%)	
Diploma	221 (22%)	63 (16%)	158 (26%)	
Bachelor	296 (30%)	178 (46%)	118 (19%)	
Postgraduate	106 (11%)	58 (15%)	48 (8%)	
Employment				
Student	4 (0%)	1 (0%)	3 (1%)	<0.001
Employee	238 (24%)	140 (36%)	98 (16%)	
Retired	412 (41%)	235 (60%)	177 (29%)	
Unemployed	346 (35%)	14 (4%)	332 (54%)	
Income (JD)				
< 250	163 (16%)	38 (10%)	125 (21%)	<0.001
250–500	534 (53%)	166 (43%)	368 (60%)	
500–800	211 (21%)	129 (33%)	82 (13%)	
> 800	92 (9%)	57 (15%)	35 (6%)	
Age (years)				
< 60	467 (47%)	183 (47%)	284 (46%)	0.870
≥ 60	533 (53%)	207 (53%)	326 (54%)	
BMI (kg/m²)				
Normal	159 (16%)	67 (17%)	92 (15%)	<0.001
Overweight	361 (36%)	166 (43%)	195 (32%)	
Obese	480 (48%)	157 (40%)	323 (53%)	

**Chi-Square test is used to compare proportions between males and females. Abbreviation: Jordan Dinar (JD)*

Table 1b: *Clinical, Chronotype, and Sleep Quality Characteristics of the Study Group (N=1000)*

Variable	Total No. (%) (n=1000)	Males No. (%) (n=390)	Females No. (%) (n=610)	*p*-value*
Family History of Diabetes				
Yes	616 (62%)	258 (66%)	358 (59%)	<0.016
No	384 (38%)	132 (34%)	252 (42%)	
Diabetes Duration (year)				
< 10	517 (52%)	183 (47%)	334 (55%)	<0.016
≥ 10	483 (48%)	207 (53%)	276 (45%)	
HbA1c (%)				
Controlled (< 7%)	519 (52%)	173 (44%)	346 (57%)	<0.001
Uncontrolled (≥ 7%)	481 (48%)	217 (56%)	264 (43%)	
Nephropathy				
Yes	151 (15%)	81 (21%)	70 (12%)	<0.001
No	849 (85%)	309 (79%)	540 (89%)	
Neuropathy				
Yes	205 (21%)	79 (20%)	126 (21%)	0.879
No	795 (80%)	311 (80%)	484 (79%)	
Retinopathy				
Yes	219 (22%)	85 (22%)	134 (22%)	0.949
No	781 (78%)	305 (78%)	476 (78%)	
Hypertension				
Yes	598 (60%)	234 (60%)	364 (60%)	0.918
No	402 (40%)	156 (40%)	246 (40%)	
Dyslipidemia				
Yes	630 (63%)	251 (64%)	379 (62%)	0.477
No	370 (37%)	139 (36%)	231 (38%)	
Cardiovascular Disease				
Yes	216 (22%)	103 (26%)	113 (19%)	<0.003
No	784 (78%)	287 (74%)	497 (82%)	
Stroke				
Yes	22 (2%)	13 (3%)	9 (2%)	0.051
No	978 (98%)	377 (97%)	601 (99%)	
Diabetes Treatment				
Oral Hypoglycemic Agents	668 (67%)	246 (63%)	422 (69%)	0.102
Insulin	28 (3%)	14 (4%)	14 (2%)	
Oral Hypoglycemic Agents + Insulin	304 (30%)	130 (33%)	174 (29%)	
Sleep Quality: shortPSQI Score				
≤ 4 (Good)	318 (32%)	120 (31%)	198 (33%)	0.576
> 4 (Poor)	682 (68%)	270 (69%)	412 (68%)	
Chronotype: rMEQ				
Definitely Morning (22–25)	113 (11%)	54 (14%)	59 (10%)	<0.001
Moderately Morning (18–21)	275 (28%)	132 (34%)	143 (23%)	
Intermediate (12–17)	421 (42%)	138 (35%)	283 (46%)	
Moderately Evening (8–11)	123 (12%)	40 (10%)	83 (14%)	
Definitely Evening (4–7)	68 (7%)	26 (7%)	42 (7%)	

**Chi-Square test is used to compare proportions between males and females. Abbreviations: reduced Morningness-Eveningness Questionnaire (rMEQ); shortened Pittsburgh Sleep Quality Index (shortPSQI).*

Chronotype, Body Mass Index, and Glycemic Control

Table 2 presents the distribution of chronotype categories by sex, BMI, and HbA1c in the study group. Significant differences (p<0.001) exist between males and females in the relationship between chronotype and BMI. In the “definitely morning type", 61% of males were overweight or obese (p<0.004), while females showed a trend of variation but did not yet meet significance (p<0.056), with 56% in this group being obese. No significant changes in chronotype across BMI groups were found (p<0.071), but a higher percentage of both sexes in "definitely morning type" and "moderately morning type" were overweight or obese. Chronotype significantly affects glycemic regulation, with a greater proportion of males with controlled HbA1c (<7) identifying as "definitely morning type" (72%) compared to those with uncontrolled HbA1c (p<0.001), and a similar association was observed in

females (p<0.025). Participants with regulated HbA1c were more likely to be "definitely morning type" (66%) and "moderately morning type" (50%), while those with uncontrolled HbA1c had a higher prevalence (p<0.001) in "moderately evening type" (64%) and "definitely evening type" (53%). Therefore, the “definitely morning type” is associated with better blood glucose regulation.

Table 2: *Distribution of Chronotype Categories by Sex, BMI, and Hba1c in The Study Group (N=1000)*

Sex	Chronotype Categories	Normal (18.5–24.9)	Overweight (25.0–29.9)	Obese (≥30.0)	Total	*p*-value	HbA1c Controlled (<7)	HbA1c Uncontrolled (≥7)	Total	*p*-value*
Males	Definitely morning	8 (15%)	33 (61%)	13 (24%)	54	<0.004	39 (72%)	15 (28%)	54	<0.001
	Moderately morning	28 (21%)	50 (38%)	54 (41%)	132		61 (46%)	71 (54%)	132	
	Intermediate	28 (20%)	57 (41%)	54 (39%)	138		54 (39%)	84 (61%)	138	
	Moderately evening	0 (0%)	19 (48%)	21 (53%)	40		8 (20%)	32 (80%)	40	
	Definitely evening	3 (12%)	8 (31%)	15 (58%)	26		11 (42%)	15 (58%)	26	
	Total	67	166	157	390		173	217	390	
Females	Definitely morning	14 (24%)	12 (20%)	33 (56%)	59	0.056	36 (61%)	23 (39%)	59	<0.025
	Moderately morning	25 (17%)	35 (24%)	83 (58%)	143		77 (54%)	66 (46%)	143	
	Intermediate	37 (13%)	98 (35%)	148 (52%)	283		176 (62%)	107 (38%)	283	
	Moderately evening	9 (11%)	34 (41%)	40 (48%)	83		36 (43%)	47 (57%)	83	
	Definitely evening	7 (17%)	16 (38%)	19 (45%)	42		21 (50%)	21 (50%)	42	
	Total	92	195	323	610		346	264	610	
Total	Definitely morning	22 (20%)	45 (40%)	46 (41%)	113	0.071	75 (66%)	38 (34%)	113	<0.001
	Moderately morning	53 (19%)	85 (31%)	137 (50%)	275		138 (50%)	137 (50%)	275	
	Intermediate	65 (15%)	154 (37%)	202 (48%)	421		230 (55%)	191 (45%)	421	
	Moderately evening	9 (7%)	53 (43%)	61 (50%)	123		44 (36%)	79 (64%)	123	
	Definitely evening	10 (15%)	24 (35%)	34 (50%)	68		32 (47%)	36 (53%)	68	
	Total	159 (16%)	361 (36%)	480 (48%)	1000		519 (52%)	481 (48%)	1000	

**Chi-Square test is used to compare proportions between males and females. Abbreviations: Body mass index (BMI), glycated hemoglobin (HbA1c)*

Sleep Quality, BMI, and HbA1c

Table 3 shows the distribution of sleep quality by sex, BMI, and HbA1c in the study group. No significant differences (p<0.753) in sleep quality were reported among BMI categories for males. Conversely, a significant correlation (p<0.001) existed between being overweight or obese and achieving good sleep quality among females. A significant correlation (p<0.035) also existed between BMI and sleep quality in the entire study group. There was no notable difference (p<0.135) between the controlled and uncontrolled HbA1c groups for males. Conversely, a significant difference (p<0.001) was observed among females. A significant correlation (p<0.001) existed between HbA1c levels and sleep quality in the entire study group.

Table 3: *Distribution of Sleep Quality by Sex, BMI, and HbA1c in the Study Group (n=1000)*

Sex	ShortPSQI score	Normal (18.5–24.9)	Overweight (25.0–29.9)	Obese (≥30.0)	Total	*p*-value	HbA1c Controlled (<7)	HbA1c Uncontrolled (≥7)	Total	*p*-value*
Males	≤4 (good)	22 (18%)	53 (44%)	45 (38%)	120		60 (50%)	60 (50%)	120	0.135
	>4 (poor)	45 (17%)	113 (42%)	112 (42%)	270	0.753	113 (42%)	157 (58%)	270	
	Total	67	166	157	390		173	217	390	
Females	≤4 (good)	38 (19%)	45 (23%)	115 (58%)	198		135 (68%)	63 (32%)	198	<0.001
	>4 (poor)	54 (13%)	150 (36%)	208 (51%)	412	<0.002	211 (51%)	201 (49%)	412	
	Total	92	195	323	610		346	264	610	
Total	≤4 (good)	60 (19%)	98 (31%)	160 (50%)	318		195 (61%)	123 (39%)	318	<0.001
	>4 (poor)	99 (15%)	263 (39%)	320 (47%)	682	<0.035	324 (48%)	358 (53%)	682	
	Total	159 (16%)	361 (36%)	480 (48%)	1000		519 (52%)	481 (48%)	1000	

**Chi-Square test is used to compare proportions between males and females. Abbreviations: Body mass index (BMI), glycated hemoglobin (HbA1c), shortened Pittsburgh Sleep Quality Index (shortPSQI)*

Factors Independently Associated with Sleep Quality

Table 4 displays the factors independently associated with sleep quality as determined by the multivariate logistic regression. The results of this test revealed the key factors linked to poor sleep quality. Overweight participants (OR=1.686, 95% CI: 1.121–2.535, p<0.012) were more likely to have poor sleep compared to those with normal BMI, while obesity showed no significant association (OR=1.080, 95% CI: 0.734–1.588, p<0.696). Uncontrolled HbA1c was strongly associated with poor sleep (OR=1.747, 95% CI: 1.309–2.331, p<0.001). Married (OR=2.167, 95% CI: 1.133–4.144, p<0.019) and divorced/widowed (OR=2.206, 95% CI: 1.058–4.597, p<0.035) participants had higher odds of sleep disturbances than singles. Nephropathy (OR=1.586, p<0.021), neuropathy (OR=1.505, p<0.035), and retinopathy (OR=1.465, p<0.042) were independently linked to poor sleep. Moderately evening types (OR=1.812, p<0.046) and definitely evening types (OR=2.213, p<0.026) had greater odds of poor sleep than morning types, while intermediates showed no significant relationship. These results highlight the influence of BMI, glycemic control, comorbidities, and chronotype on sleep quality. Participants who were overweight and those with uncontrolled HbA1c exhibited significantly higher odds of poor sleep quality after adjustment for potential confounders.

Table 4: *Factors Independently Associated with Sleep Quality as Determined by Multivariate Logistic Regression (N=1000)*

Variable	OR (95% CI)	*p*- value*
BMI		
Normal	1 (Ref)	
Overweight	1.686 (1.121 - 2.535)	<0.012
Obese	1.08 (0.734 - 1.588)	0.696
HbA1c		
Controlled (<7)	1 (Ref)	
Uncontrolled (≥7)	1.747 (1.309 - 2.331)	<0.001
Marital Status		
Single	1 (Ref)	
Married	2.167 (1.133 - 4.144)	<0.019
Divorced/widow	2.206 (1.058 -4.597)	<0.035
Nephropathy		
No	1 (Ref)	
Yes	1.586 (1.072 - 2.348)	<0.021
Neuropathy		
No	1 (Ref)	

Yes	1.505 (1.028 - 2.204)	<0.035
Retinopathy		
No	1 (Ref)	
Yes	1.465 (1.014 - 2.116)	<0.042
Chronotype (rMEQ)		
Definitely morning type	1 (Ref)	
Moderately morning type	1.194 (0.752 – 1.896)	0.453
Intermediate	1.361 (0.877 – 2.114)	0.169
Moderately evening type	1.812 (1.011 – 3.249)	<0.046
Definitely evening type	2.213 (1.099 – 4.455)	<0.026

**p-values for adjusted odds ratios from multivariate binary logistic regression. Abbreviations: reduced Morningness-Eveningness Questionnaire (rMEQ).*

Factors Independently Associated with Glycemic Control

Factors independently associated with glycemic control (HbA1c) as determined by the multivariate logistic regression are presented in Table 5. Female sex exhibited a reduced likelihood of having elevated HbA1c compared to male sex (OR=0.605, p<0.002). Compared to urban life, residing in a village significantly increased the likelihood of elevated HbA1c levels (OR=1.685, p<0.020). Participants without retinopathy demonstrated significantly lower odds of elevated HbA1c (OR = 0.598; 95% CI: 0.402-0.891, p<0.011) compared with those who had retinopathy. The type of diabetes medication had a notable association. Participants who administered insulin (OR=4.655, p<0.002) or a combination of oral hypoglycemic agents (OHA) and insulin (OR=12.973, p<.001) had a greater likelihood of elevated HbA1c levels than those receiving only OHA, likely reflecting advanced disease stage.

Table 5: *Factors Independently Associated with Hba1c as Determined by Multivariate Logistic Regression (N=1000)*

Variable	OR (95% CI)	*p*- value*
Sex		
Males	1 (Ref)	
Females	0.605 (0.437 - 0.838)	<0.002
Place of Living		
City	1 (Ref)	
Village	1.685 (1.085 - 2.615)	<0.020
Retinopathy		
Yes	1 (Ref)	
No	0.598 (0.402 - 0.891)	<0.011
Diabetes Treatment		
OHA	1 (Ref)	
Insulin	4.655 (1.759 - 12.317)	<0.002
OHA + Insulin	12.973 (8.613 - 19.539)	<0.001
Duration of Diabetes (years)		
< 10 years	1 (Ref)	
>= 10 years	2.739 (1.982 - 3.786)	<0.001
Sleep Quality: shortPSQI Score		
<=4 (Good)	1 (Ref)	
> 4 (Poor)	1.418 (1.011 - 1.988)	<0.043
Chronotype: rMEQ		
Definitely morning type (22-25)	1 (Ref)	
Moderately morning type (18-21)	2.564 (1.423 - 4.619)	<0.002
Intermediate (12-17)	2.033 (1.159 - 3.566)	<0.013
Moderately evening type (8-11)	3.727 (1.850 - 7.506)	<0.001
Definitely evening type (4-7)	2.174 (0.953 - 4.961)	0.065

**p-values for adjusted odds ratios from multivariate binary logistic regression.*
Abbreviations: reduced Morningness-Eveningness Questionnaire (rMEQ); shortened Pittsburgh Sleep Quality Index (shortPSQI); Oral Hypoglycemic Agents (OHA).

Participants with diabetes duration of 10 years or more exhibited a higher likelihood of elevated HbA1c (OR=2.739, p<0.001). The shortPSQI score indicated that participants with poor sleep quality (>4) were more likely to have elevated HbA1c levels (OR=1.418, p<0.043). The rMEQ score was also correlated with HbA1c. In comparison to definite morning types, moderately morning types

(OR=2.564, p<0.002), intermediate types (OR=2.033, p<0.013), and moderately evening types (OR=3.727, p<0.001) exhibited higher odds. The definite evening type did not reach statistical significance (OR=2.174, p<0.065).

Discussion

This study investigated the complex relationships between chronotype, sleep quality, BMI, and HbA1c levels in participants with T2D, with a particular focus on potential sex-specific characteristics. The results reveal that behavioral and circadian factors play an important role in determining metabolic outcomes and influencing the risk of overweight and obesity in T2D. These findings emphasize the necessity of considering these factors in managing and preventing diabetes, as they may significantly relate to health outcomes in this condition.

In the present study, we found that morning chronotypes are predominant among both normal and overweight males, whereas evening chronotypes are significantly associated with obesity. A similar pattern emerged in females, although it fell just short of statistical significance (p<0.056). Research has reinforced these findings, revealing that evening chronotypes tend to have a higher BMI, elevated levels of ghrelin, and poorer dietary habits (Erim & Sert, 2023). In T2D, recent evidence has explicitly demonstrated that individuals with an evening chronotype experience significantly higher BMI and poorer glycemic control due to circadian misalignment (Siddaraju *et al.,*2026). However, some studies reported no significant connection between chronotype and BMI (McMahon *et al.,* 2019; Baek *et al.,* 2024). One study found no direct link between obesity and chronotype but observed that morning types who experienced poor sleep had higher body fat percentages and greater waist-to-hip ratios (McMahon *et al.,* 2019). Another study indicated that morning types in a different cultural context had larger waist sizes while maintaining stable BMI levels (Baek *et al.,* 2024). Sleep also played a more pronounced role in influencing BMI among females, possibly due to hormonal or lifestyle factors (Yeom & Lee, 2020). Further evidence established stronger links between sleep quality and obesity in females, indicating heightened metabolic sensitivity (Fan *et al.,* 2021). A study of patients recently diagnosed with T2D revealed a U-shaped relationship between weekday sleep and fasting blood glucose levels, and about 7 hours of sleep is ideal for managing blood glucose effectively; however, the relationship of sex with these findings was not explored (Xu *et al.,* 2026). The discrepancies in findings may arise from various factors, including cultural and lifestyle differences, specific study cohorts, experimental methods, and the criteria used to classify chronotypes.

Chronotype is significantly associated with glycemic control, particularly in males. Morning types consistently achieve superior HbA1c levels, whereas evening chronotypes struggle with poorer control. These findings are supported by several studies on patients with T2D (Anothaisintawee *et al.,* 2016; Siddaraju *et al.,*2026). Research indicated that evening chronotypes often have elevated HbA1c levels, even after accounting for sleep patterns and insomnia (Hashemipour *et al.,* 2020). Further, evidence suggests that evening types face associate with poorer glycemic control, independent of body weight or duration of disease (Docimo *et al.,* 2023; Siddaraju *et al.,*2026). There is also a concerning link between late-night eating habits in evening types, which can disrupt natural circadian rhythms and diminish insulin sensitivity, potentially exacerbating glycemic control issues (Chandorkar *et al.,* 2023). However, no significant association has been found in patients with prediabetes or those newly diagnosed (Mokhlesi *et al.,* 2019). While analysing dietary drivers contributing to elevated BMI and poor glycemic control in metabolic conditions, a recent study has shown how chronotype preferences are inversely associated with overall sleep quality and highlighted how circadian rhythms modulate physiological factors, such as BMI (Ulutaş *et al*., 2026). The vast majority of research (Anothaisintawee *et al.,* 2016; Hashemipour *et al.,* 2020; Docimo *et al.,* 2023; Chandorkar *et al.,* 2023), including our own, strongly supports the notion that chronotype is a vital behavioral factor in managing glycemic control, highlighting the importance of understanding this aspect in developing effective strategies for diabetes management and overall health.

Sleep quality is significantly linked to BMI, particularly in females. Overweight and obese females consistently report more sleep-related issues, emphasizing a crucial concern. This finding aligns with

previous research that demonstrated a clear association between poor sleep, female sex, and elevated BMI in a Chinese cohort (Hung *et al*., 2013). Moreover, a notable statistic revealed that females who experience insufficient sleep are 62% more likely to be obese and 22% more likely to accumulate visceral fat compared to their male counterparts (Fan *et al.,* 2021). Further insights highlighted the significant association of sleep with BMI in females, stemming from various physiological and lifestyle factors (Yeom & Lee, 2020). Potential contributors to this result include hormonal fluctuations, such as increased ghrelin and reduced leptin levels, as well as lifestyle behaviors like overeating and physical inactivity (Günal, 2023). However, the absence of significant differences in males may be due to a lower sensitivity to sleep deprivation and the adoption of differing coping mechanisms and health strategies (Hung *et al*., 2013; Yeom & Lee, 2020; Fan *et al.,* 2021; Günal, 2023). Interestingly, overweight status remained significantly associated with poor sleep quality, whereas obesity did not retain significance in the adjusted model. This finding may reflect residual confounding, differences in sample distribution, or limitations of BMI as a surrogate measure of adiposity and metabolic health.

Sleep quality is significantly associated with HbA1c levels among participants, particularly in females. Research demonstrated that improved sleep is associated with better HbA1c outcomes for women (Tsai *et al.,* 2012). Conversely, other findings highlighted a marked eightfold increase in the risk of uncontrolled diabetes linked to poor sleep patterns (Kianersi *et al.,* 2023). Furthermore, inadequate sleep has been confirmed to correlate with elevated HbA1c levels, with a pronounced relationship in females and smokers (Ayaz & Dincer, 2021). These results are consistent with well-established evidence that sleep deprivation negatively affects hormones, such as leptin and ghrelin, leading to increased appetite and increased insulin resistance (Darroudi *et al.,* 2021). Notably, 82% of patients with diabetes experience sleep disturbances, evidenced by high PSQI scores above 5 (Hamayal *et al.,* 2025). Moreover, over half of the participants had PSQI scores exceeding a critical threshold (over 8), underscoring the prevalence and seriousness of sleep issues (Cappuccio *et al.,* 2010). However, it is essential to acknowledge that some research also found no substantial link between sleep and glycemic control (Al Nefaie *et al*., 2022; Darraj, 2023). This discrepancy may result from differences in assessment tools, cultural attributes, lifestyle factors, or diabetes duration and severity. There is also a call for larger, community-based studies with objective sleep measures to provide a clearer understanding of the critical relationship between sleep and diabetes management (Farooque *et al.,* 2020).

This study revealed critical independent factors significantly associated with poor sleep quality, including overweight status, uncontrolled HbA1c levels, marital status, and diabetic complications. Specifically, participants classified as overweight have markedly higher odds of experiencing poor sleep (OR=1.686, p<0.012). This finding is consistent with the MASHAD cohort study, which highlighted the detrimental association of excess weight with sleep duration (Darroudi *et al.,* 2021). A significant underlying contributor may be obstructive sleep apnoea, a common condition in obesity that disrupts sleep through episodes of hypoxia and fragmentation Moreover, poor sleep may contribute to weight gain by increasing ghrelin levels, decreasing leptin levels, impairing glucose metabolism, and reducing energy expenditure (Darroudi *et al.,* 2021). Furthermore, it has been demonstrated that poor sleep (PSQI) efficiency strongly correlates with higher glycemic variation, making sleep a crucial modifiable lifestyle factor alongside BMI management in T2D (Hussain *et al*., 2025). Magalhães *et al*. (2026) documented that the risk cycle where later chronotypes and lower sleep efficiency directly prompt poorer dietary habits, which subsequently act as confounding pathways to high BMI and compromised metabolic profiles. Notably, uncontrolled HbA1c levels (≥7%) correlate with poor sleep quality (OR=1.747, p<0.001). This correlation is further substantiated by a meta-analysis of 15 studies with T2D (Lee *et al.,* 2017). Married participants (OR=2.167, p<0.019) and those who are divorced or widowed (OR=2.206, p<0.035) exhibit poorer sleep compared to their single counterparts. While some research suggested that marriage may enhance sleep through emotional and biological support (Brown *et al.,* 2019), it is crucial to recognize that life transitions, such as divorce or widowhood, can severely undermine sleep quality, underscoring the profound links

of social stress (August, 2022). These insights highlight the complex relationships between lifestyle factors and sleep, underscoring the urgent need for targeted interventions to enhance sleep quality, particularly in vulnerable populations.

Nephropathy is significantly associated with poor sleep, with an odds ratio of 1.586 and a statistically significant *p*-value of <0.021. A cohort study suggested that extended sleep duration is correlated with a heightened risk of diabetic kidney disease, showcasing a hazard ratio of 1.47 and a robust 95% confidence interval of 1.19–1.81 (Liu *et al.,* 2023). Neuropathy significantly disrupts sleep quality (OR=1.505, $p<0.035$), as increased sleep latency leads to reduced sleep duration, lower efficiency, and more interruptions due to neuropathic pain (Melikoglu & Celik, 2017). Furthermore, retinopathy significantly increased the risk of poor sleep, backed by an odds ratio of 1.465 ($p<0.042$). A comprehensive meta-analysis underscored that poor sleep is associated with the risk of retinopathy, with particularly detrimental links with photosensitive retinal ganglion cells (Zheng *et al.,* 2022). Although this study focused on nephropathy, this evidence collectively emphasized the critical relationship between sleep health and serious diabetic complications.

Evening chronotypes are significantly more susceptible to sleep disturbances than their morning counterparts, reinforcing existing reviews that link late chronotypes to diminished sleep quality and increased metabolic risks (Zheng *et al.,* 2022). This study successfully identified key factors associated with elevated HbA1c levels. Notably, females exhibit lower odds of high HbA1c compared to males (OR=0.605, $p<0.002$), supporting research that emphasizes women's superior diabetes self-care (Hezaveh *et al.,* 2024). Moreover, villagers encounter even greater challenges, with a significant increase in the likelihood of poor glycemic control (OR=1.685, $p<0.020$). This finding underscored the profound relationship with limited access to healthcare and education in rural areas, a reality affirmed by research on rural health disparities (Singh *et al.,* 2022).

The absence of retinopathy has been clearly associated with a much lower risk of elevated HbA1c levels (OR=0.598, $p<0.011$), underscoring the important understanding that sustained hyperglycaemia is a major factor in microvascular damage (Khatoon *et al.,* 2023). Furthermore, the use of insulin (OR=4.655) and the implementation of combined therapy (OR=12.973) are strongly associated with poor glycemic control. This insight likely indicates a trend toward more intensive treatment strategies in cases of mismanaged diabetes (Aldafas *et al.,* 2025). Having diabetes for 10 years or longer significantly raises the risk of elevated HbA1c levels (OR=2.739, $p<0.001$), indicating a continued decline in beta-cell function over time (Inzucchi *et al.,* 2015). Moreover, poor sleep quality, indicated by a PSQI score above 4, increases this risk (OR=1.418, $p<0.043$), highlighting that sleep deprivation significantly disrupts glucose metabolism and overall health (Seshadri *et al,* 2024). The observed association between insulin-based therapy and elevated HbA1c likely reflects greater disease severity, longer disease duration, and treatment intensification among individuals requiring insulin therapy. Therefore, the findings should not be interpreted as evidence that insulin treatment adversely affects glycemic control.

The association between chronotype and HbA1c levels is important. Participants with a moderately morning chronotype exhibited an odds ratio of 2.56 ($p<0.002$), while those with an intermediate chronotype had an odds ratio of 2.03 ($p<0.013$). Remarkably, individuals with a moderately evening chronotype showed the highest odds ratio of 3.73 ($p<0.001$). These data underscore a significant trend: all these chronotype groups have notably higher odds of elevated HbA1c levels compared to morning types, highlighting the potential consequences of circadian misalignment on metabolic health (Siddaraju*et al.,* 2026). In essence, the findings support previous evidence suggesting that evening chronotype is associated with poorer metabolic outcomes and less favorable sleep characteristics. However, due to the cross-sectional design, temporal and causal relationships cannot be established.

Limitations and Strengths

The primary limitations of this study stem from its cross-sectional design, which hinders the ability to establish causal relationships and instead merely highlights correlations without indicating a temporal sequence. Although stronger associations were observed among males in selected analyses,

interaction analyses were not performed. Therefore, these findings should be considered exploratory and interpreted cautiously until confirmed by future studies. Several potential confounding factors were not assessed, including obstructive sleep apnoea, insomnia, shift-work status, smoking habits, physical activity, dietary intake, medication adherence, psychological stress, anxiety, depression, caffeine consumption, and socioeconomic status. These variables may have influenced the observed associations. Moreover, recruitment from a specialized diabetes centre may limit generalizability to broader populations with T2D. Another limitation is the reliance on self-reported measures for chronotype and sleep quality, which may be subject to recall and social desirability bias. Objective assessments such as actigraphy, polysomnography, or continuous sleep monitoring were not utilized, yet they could provide more precise estimates of sleep-related parameters.

Despite its limitations, this study presents many strengths. The strong sample size significantly enhances the validity of the findings, while the use of validated instruments, such as the rMEQ and shortPSQI, guarantees precise and reliable measurements. Furthermore, the investigation of interconnected factors: BMI, chronotype, sleep quality, and glycemic control, offers an insightful and comprehensive perspective on diabetes-related behaviors. Notably, the sex-segregated analysis reveals distinct and clinically significant patterns, highlighting the subtle nature of the data and its implications for effective diabetes management.

Future Scope

Future studies should employ longitudinal and prospective designs to clarify the temporal and causal relationships among chronotype, sleep quality, BMI, and glycemic control in individuals with T2D. Incorporating objective sleep assessments and a broader range of behavioral, psychological, and clinical factors may provide a more comprehensive understanding of these associations and support the development of targeted interventions.

Conclusion

In conclusion, evening chronotype and poor sleep quality were associated with less favourable metabolic outcomes among adults with T2D. Poor sleep quality was associated with overweight status and elevated HbA1c, whereas chronotype was associated with glycemic control. Because of the cross-sectional nature of the study, causal inferences cannot be drawn. Future prospective and interventional studies are needed to clarify the directionality and mechanisms underlying these relationships.

Author Contributions

MNA, EMH, NMK, and YSK: Contributed to the study design, data collection, analysis, and to writing the manuscript. KMA: Contributed to study design and to writing the manuscript. All authors have read, revised, and approved the manuscript.

Conflicts of Interest

The authors declare that they have no competing interests.

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