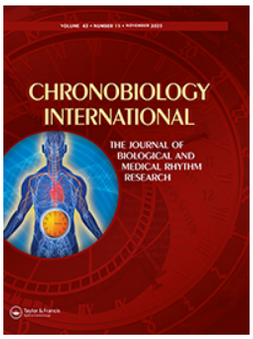

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Associations of sleep duration and quality with risk of incident obesity, diabetes, and metabolic syndrome: Results from the Midlife in the United States study

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ABSTRACT

Understanding how sleep affects the risk of incident chronic conditions in midlife may reinforce the importance of a healthy sleep pattern for healthy aging and cardiometabolic health. The objective of the study was to examine associations of sleep duration and quality with incident obesity, diabetes and metabolic syndrome in mid-aged adults. Participants without obesity (n = 381), diabetes (n = 509), or metabolic syndrome (n = 487) from the Biomarker Projects in Midlife in the United States study were examined separately for baseline sleep duration and quality and their associations with incident obesity, diabetes, or metabolic syndrome after an average follow-up of 12 years. There was no significant association between baseline sleep duration and any of the incident conditions at follow-up ($p > 0.05$ for all). However, participants with poor baseline sleep quality had a higher risk of incident obesity (odds ratio (OR) = 1.798, 95% confidence interval (CI)= (1.001, 3.229), $p = 0.0497$) and incident diabetes (OR = 2.499, 95% CI=(1.160, 5.383), $p = 0.0194$) at follow-up than those with good sleep quality. There was no significant association between sleep quality and incident metabolic syndrome (OR = 0.881, 95% CI=(0.547, 1.420), $p = 0.6031$). In conclusion, sleep quality was associated with incident obesity and diabetes; maintaining a healthy sleep pattern in midlife may help reduce risk for these chronic conditions.

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Sleep quality; sleep duration; obesity; diabetes; metabolic syndrome

Introduction

Sleep disturbances, such as short sleep duration and poor sleep quality, are widespread. In the United States, 33% of adults reported short sleep duration (Pankowska et al. 2023) and 15% reported having trouble staying asleep (Adjaye-Gbewonyo et al. 2022). These problems have become a public health burden, due not only to loss of productivity and increased risk of accidents (Saleem 2022), but also increased risk of various chronic diseases and all-cause mortality (Denney et al. 2023).

Obesity, diabetes, and metabolic syndrome are prevalent chronic conditions that are associated with sleep disturbance (Li et al. 2022). For example, previous studies have reported short sleep duration or poor sleep quality is associated with obesity (Hur et al. 2021; Xu et al. 2025), diabetes (Li et al. 2025; Noga et al. 2024), and metabolic syndrome (Che et al. 2021; Liang et al. 2023). Although the causal relationship remains to be elucidated, various mechanisms have been proposed. Principally, sleep disturbance such as insufficient sleep duration can alter several physiological pathways leading to increased pro-inflammatory cytokines, sympathetic activity, oxidative stress, and ghrelin, as well as reduced leptin. In turn, these alterations can lead to increased appetite and food intake, decreased pancreatic beta-cell responsiveness, and endothelial dysfunction, contributing to chronic conditions such as obesity, diabetes, and metabolic syndrome Tobaldini et al. (2019).

As revealed by various systematic reviews and meta-analyses on this topic (Che et al. 2021; Hu et al. 2022; Jiang et al. 2024; Liu et al. 2025; Xie et al. 2021), most studies examining sleep-related measures in relation to obesity, diabetes or metabolic syndrome have been cross-sectional. Furthermore, most of these studies have focused on either sleep duration or sleep quality rather than evaluating both concurrently. Longitudinal studies that assess both sleep duration and quality are needed to strengthen the evidence base (Bacaro et al. 2020; Jiang et al. 2024). Additionally, research specifically targeting middle-aged adults remains limited, despite midlife being a critical stage of life with a heightened risk for developing metabolic disorders (Watson et al. 2025). Importantly, modifiable lifestyle and behavioural factors during midlife can promote healthy aging (Tessier et al. 2025) and enhance quality of life in late adulthood (Nguyen et al. 2024). To the best

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of our knowledge, no longitudinal study has comprehensively investigated the synergistic effects of both sleep duration and quality on measures and risk of incident obesity, diabetes, and metabolic syndrome in midlife. Therefore, the objective of this study was to examine associations between both sleep duration and sleep quality and the risk of incident obesity, diabetes, and metabolic syndrome in a group of healthy middle-aged adults in the United States.

Materials and Methods

Data Source

The Midlife in the United States (MIDUS) study is a multi-centre longitudinal observational study initiated in 1995 to examine lifestyle, physical and mental health in midlife (Brim et al. 2004). Details of the study design and outcomes of measurement have been described previously (Brim et al. 2004). Participants from the MIDUS 1 study were followed up for the MIDUS 2 study in 2004–2005; a subset of participants later completed the Biomarker Project, in which they visited one of the research facilities for a physical exam with an overnight stay in 2004–2009 (Love et al. 2010). The Biomarker Project included the Pittsburgh Sleep Quality Index (PSQI) survey and biometric measures, among other questionnaires and tests (Love et al. 2010). Starting in 2013, participants were followed up for the MIDUS 3 study, and a subset of participants completed the Biomarker Project in MIDUS 3 in 2017–2022 with similar protocols.

The present study used data from the Biomarker Project in MIDUS 2 and MIDUS 3. The Biomarker Projects in MIDUS were approved by the Institutional Review Board from the University of Wisconsin – Madison; all participants provided their informed consent. The data from MIDUS is publicly available. This study is exempt from IRB review as it involves a secondary analysis of a publicly available dataset.

Study Population

The present study initially included 687 participants who completed both Biomarker Projects in MIDUS 2 (baseline) and MIDUS 3 (follow-up). Participants with missing PSQI information from MIDUS 2, and those without body weight or laboratory measures to assess obesity, diabetes, or metabolic syndrome status in both MIDUS 2 and MIDUS 3 were excluded. Participants without obesity in MIDUS 2 were included as the obesity study cohort and were used for analysis of incident obesity in MIDUS 3. Similarly, participants without diabetes or metabolic syndrome were included as the diabetes study cohort or the metabolic syndrome study cohort and used for analysis of incident diabetes or incident metabolic syndrome in MIDUS 3, respectively. These three study cohorts were not mutually exclusive; for example, if a participant did not have obesity and diabetes in MIDUS 2, then the participant would be included in both the obesity study cohort and the diabetes study cohort. Overall, there were 605 participants included in at least one of the three study cohorts. There were 381 participants in the obesity study cohort, 509 participants in the diabetes study cohort, and 487 participants in the metabolic syndrome cohort.

Exposure Variables

The PSQI from MIDUS 2 was used as a baseline measurement for subjective sleep duration and quality, which served as exposure variables in the study. The PSQI is a validated survey for self-rated sleep measures in the past month. The survey questions are categorized and graded for seven component scores that are added together for a global score with a range of 0–21 points as an indicator of sleep quality (Buysse et al. 1989). A score of 0–5 represents good sleep quality, whereas a score of 6 or more represents poor sleep quality (Buysse et al. 1989). As a sensitivity analysis for sleep quality, a three-level categorization was created: 0–5 for good sleep quality, 6–10 for poor sleep quality, and 11–21 for very poor sleep quality (Ko et al. 2012). The PSQI also included a question on the number of hours of actual sleep per night in the past month, which was used as a measure for subjective sleep duration. Participants who reported an average of less than 7 hours of sleep per night were considered to have short sleep duration, and those with an average of at least 7 hours of sleep per night were considered to have recommended sleep duration (Gordon et al. 2022).

Outcomes Variables

Whether participants had obesity, diabetes, or metabolic syndrome in MIDUS 3 was the outcome for each study cohort. For example, in the obesity study cohort, the outcome was whether participants developed incident obesity by MIDUS 3. Obesity was defined as a body mass index of ≥30 kg/m^2. Diabetes was defined as glycated haemoglobin (HbA1c) ≥6.5%, or fasting glucose ≥126 mg/dL, or self-reported diabetes history (American Diabetes Association 2020). Metabolic syndrome was defined as the presence of at least three of the following five conditions: elevated waist circumference (> 40 inches for men or > 35 inches for women),

elevated triglycerides (≥150 mg/dL), reduced high-density lipoprotein (< 40 mg/dL for men or < 50 mg/dL for women), elevated blood pressure (≥130/80 mmHg or self-reported hypertension), and elevated fasting glucose (≥110 mg/dL) (Grundy et al. 2004).

Covariates

The full list of covariates included age, sex, race, education, smoking status, physical activity level, self-reported physical and mental health, and years of follow up, defined as the number of years between the Biomarker Projects in MIDUS 2 and MIDUS 3. Physical activity level was defined by metabolic equivalent of task minutes (MET-minutes) per week, a measurement of weekly physical activities based on type and duration of self-reported physical activities. The value was categorized as 0, 1–499, 500–999, 1000–1499, and ≥1500 MET-min/week (Jeong et al. 2019). Self-reported physical health and self-reported mental health were both assessed by a Likert scale that included a rating from five categories: excellent, very good, good, fair, and poor; the first three ratings were combined as the "good" category and the last two ratings were grouped into the "poor" category (Oftedal et al. 2019). Baseline BMI was not included as a covariate because of its collinearity with existing covariates.

Statistical Analysis

SAS 9.4 (SAS Institute, Cary, NC, USA) was used for statistical analysis. Tukey's fence was used to detect outliers for continuous variables (Schwertman and de Silva 2007); those identified as outliers were set as missing values for that variable. Baseline characteristics for the overall population and each study cohort were presented as mean and standard deviation for continuous variables, or number and percentage for categorical variables. In each study cohort, the associations between baseline sleep quality and the outcome at follow-up were examined using logistic regression analysis with good sleep quality as the reference group; the associations between baseline sleep duration and the outcome at follow-up were examined using logistic regression analysis, using recommended sleep duration as the reference group. For example, in the obesity study cohort, associations between baseline sleep quality or sleep duration and incident obesity at follow-up were examined. For each outcome, three models were assessed: an unadjusted model, an adjusted model with age, sex, and race as covariates, and a fully adjusted model with all covariates examined. For the sensitivity analysis of sleep quality as a 3-level variable, multinomial logistic regression analysis was used with good sleep quality as the reference group. Odds ratio (OR) and 95% confidence interval (CI) were presented for each model. $p \leq 0.05$ was considered to be statistically significant.

Results

Characteristics of Participants & Incident Disease

Baseline characteristics of participants in the overall population and each study cohort are presented in Table 1. Participants had a mean age of 54 years at baseline in each study cohort. While the exact percentages varied slightly depending on the study cohort, over half of the participants were females (55–56%), about half had a bachelor's degree or higher education (45–-51%), and approximately one-third of participants had at least 1500 MET-min/week of physical activity (31–-33%). Most participants were white (80–86%), non-smokers (55–57%), and self-reported having good physical health (81–86%) and good mental health (81–86%). At baseline, 56–59% of participants had good sleep quality and 55–58% of participants had recommended sleep duration.

The average length of follow up for all study cohorts was 12 ± 1 years. In the obesity study cohort, 64 participants (16.8%) were obese at the follow-up. In the diabetes study cohort, 41 participants (8.1%) had diabetes at the follow-up. In the metabolic syndrome study cohort, 103 participants (21.2%) had metabolic syndrome at the follow-up.

Associations Between Sleep Quality and Obesity, Diabetes, and Metabolic Syndrome

Table 2 presents associations between baseline sleep quality and incident obesity, diabetes, and metabolic syndrome at follow-up. In the obesity study cohort, the unadjusted model (model 1) revealed that participants with poor sleep quality had a significantly higher risk of obesity compared to those with good sleep quality (OR = 1.738, 95% CI=(1.008, 2.997), $p = 0.0469$). The association became borderline significant in model 2 when adjusted for age, sex, and race ($p = 0.0667$). In the fully adjusted model, those with poor sleep quality had a significantly higher risk of obesity compared to those with good sleep quality (OR = 1.798, 95% CI= (1.001, 3.229), $p = 0.0497$).

In the diabetes study cohort, associations between sleep quality and diabetes did not reach statistical significance in the unadjusted model ($p = 0.0591$).

Table 1. Baseline characteristics of participants in the overall population and each study cohort.

	Overall Population (*N* = 605)		Obesity Study Cohort[a] (*N* = 381)		Diabetes Study Cohort[b] (*N* = 509)		Metabolic Syndrome Study Cohort[c] (*N* = 487)	
Characteristics	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	53.8	9.8	54.3	9.9	53.6	9.9	53.9	9.9
Body weight (kg)	82.9	17.7	73.9	12.1	82.1	17.5	80.3	17.2
Body mass index (kg/m^2)	28.5	5.0	25.6	2.7	28.4	5.0	27.6	4.7
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Sex								
Male	273	45.1	170	44.6	223	43.8	213	43.7
Female	332	54.9	211	55.4	286	56.2	274	56.3
Race/ethnicity								
White	489	80.8	327	85.8	428	84.1	388	79.7
Black/Asian/Native American	36	6.0	18	4.7	28	5.5	30	6.2
Unknown	80	13.2	36	9.5	53	10.4	69	14.2
Education								
High school or less	103	17.0	54	14.2	92	18.1	79	16.2
Associate degree	151	25.0	96	25.2	123	24.2	117	24.0
Bachelor degree	130	21.5	92	24.2	115	22.6	103	21.2
Graduate study	140	23.1	102	26.8	125	24.6	118	24.2
Unknown	81	13.4	37	9.7	54	10.6	70	14.4
Smoking status								
Current smoker	91	15.0	59	15.5	73	14.3	72	14.8
Former smoker	172	28.4	105	27.6	143	28.1	144	29.6
No smoker	341	56.4	216	56.7	292	57.4	270	55.4
Unknown	1	0.2	1	0.3	1	0.2	1	0.2
MET-minutes/week								
0	112	18.5	61	16.0	91	17.9	86	17.7
1–999	217	35.9	134	35.2	181	35.6	168	34.5
1000–1499	83	13.7	59	15.5	73	14.3	73	15.0
≥1500	189	31.2	125	32.8	160	31.4	157	32.2
Unknown	4	0.7	2	0.5	4	0.8	3	0.6
Physical health								
Good	490	81.0	328	86.1	428	84.1	392	80.5
Poor	35	5.8	17	4.5	28	5.5	26	5.3
Unknown	80	13.2	36	9.5	53	10.4	69	14.2
Mental health								
Good	492	81.3	327	85.8	430	84.5	394	80.9
Poor	33	5.5	18	4.7	26	5.1	24	4.9
Unknown	80	13.2	36	9.5	53	10.4	69	14.2
Sleep quality								
Good	323	55.0	218	58.9	274	55.6	264	55.7
Poor	264	45.0	152	41.1	219	44.4	210	44.3
Sleep duration								
Recommended	337	56.4	215	57.3	292	57.9	262	54.5
Short	261	43.7	160	42.7	212	42.1	219	45.5

Note: SD: standard deviation. Numbers may not add to the total number because outliers were excluded. [a]Obesity study cohort was defined as participants from the overall population who did not have obesity at baseline. [b]Diabetes study cohort was defined as participants from the overall population who did not have diabetes at baseline. [c]Metabolic syndrome study cohort was defined as participants from the overall population who did not have metabolic syndrome at baseline.

However, both adjusted models indicated that participants with poor sleep quality had a significantly higher risk of developing diabetes compared to those with good sleep quality; in the fully adjusted model, the risk of diabetes for participants with poor sleep quality was 150% higher than participants with good sleep quality (OR = 2.499, 95% CI=(1.160, 5.383), $p = 0.0194$).

In the metabolic syndrome cohort, associations between sleep quality and metabolic syndrome were not significant, and the findings were consistent in all three models ($p > 0.05$ for all).

Results from the sensitivity analysis with 3-level sleep quality scoring are presented in Supplementary Table S1. Participants with very poor sleep quality had a significantly higher risk of obesity compared to those with good sleep quality in all three models ($p < 0.05$ for all). Participants with poor sleep quality had a significantly higher risk of diabetes compared to those with good sleep quality in both adjusted models ($p < 0.05$ for both). Associations between sleep quality and metabolic syndrome were not significant in any models ($p > 0.05$ for all).

Associations Between Sleep Duration and Obesity, Diabetes, and Metabolic Syndrome

Table 3 presents associations between baseline sleep duration and incident obesity, diabetes, and metabolic syndrome at follow-up. Having a short sleep duration at baseline was not associated with obesity, diabetes, or

Table 2. Associations between baseline sleep quality and incident obesity, diabetes, and metabolic syndrome at follow-up.

	Odds ratio	95% Confidence Interval	*P* value
Obesity			
Model 1			
Poor vs good quality	1.738	(1.008, 2.997)	**0.0469**
Model 2			
Poor vs good quality	1.693	(0.964, 2.971)	0.0667
Model 3			
Poor vs good quality	1.798	(1.001, 3.229)	**0.0497**
Diabetes			
Model 1			
Poor vs good quality	1.928	(0.975, 3.814)	0.0591
Model 2			
Poor vs good quality	2.071	(1.017, 4.218)	**0.0448**
Model 3			
Poor vs good quality	2.499	(1.160, 5.383)	**0.0194**
Metabolic syndrome			
Model 1			
Poor vs good quality	0.935	(0.599, 1.460)	0.7676
Model 2			
Poor vs good quality	0.876	(0.556, 1.380)	0.5676
Model 3			
Poor vs good quality	0.881	(0.547, 1.420)	0.6031

Note: Model 1: Unadjusted. Model 2: Adjusted for age, sex, and race. Model 3: Adjusted for age, sex, race, education, smoking status, physical activity level, self-reported physical health, self-reported mental health, years of follow up. Good quality: PSQI total score ≤ 5. Poor quality: PSQI total score > 5. Values in bold are significant at the p < 0.05 level.

Table 3. Associations between baseline sleep duration and incident obesity, diabetes, and metabolic syndrome at follow-up.

	Odds ratio	95% Confidence Interval	*P* value
Obesity			
Model 1			
Short vs recommended sleep duration	0.933	(0.539, 1.617)	0.8059
Model 2			
Short vs recommended sleep duration	0.856	(0.486, 1.507)	0.5898
Model 3			
Short vs recommended sleep duration	0.892	(0.499, 1.596)	0.7011
Diabetes			
Model 1			
Short vs recommended sleep duration	1.417	(0.742, 2.705)	0.2911
Model 2			
Short vs recommended sleep duration	1.217	(0.626, 2.369)	0.5626
Model 3			
Short vs recommended sleep duration	1.306	(0.645, 2.646)	0.4586
Metabolic syndrome			
Model 1			
Short vs recommended sleep duration	0.799	(0.513, 1.244)	0.3204
Model 2			
Short vs recommended sleep duration	0.719	(0.455, 1.136)	0.1571
Model 3			
Short vs recommended sleep duration	0.772	(0.482, 1.238)	0.2828

Note: Model 1: Unadjusted. Model 2: Adjusted for age, sex, and race. Model 3: Adjusted for age, sex, race, education, smoking status, physical activity level, self-reported physical health, self-reported mental health, years of follow up. Short sleep duration: < 7 hours. Recommended sleep duration: ≥7 hours.

metabolic syndrome at follow-up, compared to participants who had recommended sleep duration, in both unadjusted and adjusted models ($p > 0.05$ for all).

Discussion

The present study found that self-reported poor sleep quality was associated with increased risk of incident obesity and diabetes, but not metabolic syndrome in the MIDUS cohort; however, self-reported short sleep duration was not associated with any of these conditions.

Several studies have investigated relations between sleep and obesity, diabetes-related measures, or metabolic syndrome using cross-sectional data from the MIDUS cohort, which reported the following findings: total sleep time was negatively associated with body mass index (Mezick et al. 2014; Schreiber and Dautovich 2019); sleep quality was negatively associated with prevalent obesity (Ko 2013) and metabolic syndrome (Nevels et al. 2023); and sleep onset latency was positively associated with insulin resistance (Kim et al. 2016). Results from the present study, in which the average follow-up period was over 12 years, add to the evidence that sleep quality in midlife is associated with incident obesity and diabetes. Conversely, sleep duration was not associated with any of the outcomes examined in the present study. Previous systematic reviews and meta-analyses have consistently associated short sleep duration with increased risk of obesity (Guimaraes et al. 2022; Jiang et al. 2024) and diabetes (Liu et al. 2025; Lu et al. 2021); whereas the association between short sleep duration and metabolic syndrome has had conflicting results. For example, a 2013 meta-analysis of cohort studies did not show a significant association between short sleep duration and metabolic syndrome (Ju and Choi 2013); however, more recent meta-analyses revealed a significantly increased risk of metabolic syndrome associated with short sleep duration (Che et al. 2021; Hu et al. 2022; Liang et al. 2023; Xie et al. 2021). It should be noted that there were only three cohort studies included in the 2013 meta-analysis (Ju and Choi 2013), which may have contributed to their null findings. The present study did not find a significant association between sleep duration and any of the incident conditions examined. This may be because only a small proportion (14%) of participants reported having less than 6 hours of sleep per night in the present study (data not shown). As such, all those below the recommended number of sleep hours (< 7 hours) were combined into a single group and the degree of sleep insufficiency was not able to be adequately taken into consideration but may have affected the association. This is supported by a meta-analysis

that examined the dose-response association between sleep duration and obesity from cohort studies, and found the risk of obesity increased by 8% in those with 6 hours of sleep compared to 7 hours, but exponentially increased by 22% in those with 5 hours of sleep and by 37% in those with 4 hours of sleep (Zhou et al. 2019). Similarly, the dose-response relationship from pooled studies of sleep duration and diabetes showed a similar U-shape with the risk being the lowest when participants reported 7–8 hours of sleep (Liu et al. 2025).

Poor sleep quality was associated with increased risk of obesity in the unadjusted model in the present study. Adjusting for demographic characteristics slightly attenuated the association, however, further adjustment for self-reported information such as physical activity, physical health and mental health, and smoking status resulted in a similarly significant result as the unadjusted model. In addition, when those with poor sleep quality were further classified into two categories by the PSQI total score, participants with very poor sleep quality (PSQI total score ≥ 11), but not those with a PSQI total score of 6–10, had a significantly higher risk of obesity in all models examined, even though only 7% of participants had very poor sleep quality (data not shown). A previous review summarizing studies that examined sleep quality and obesity concluded studies generally support a negative association between sleep quality and obesity (Norton et al. 2018). Nonetheless, the definition and measurement of sleep quality varied across studies and certain studies used a specific aspect of sleep that was measured instead of an overall composite score as a proxy for sleep quality. Moreover, how severity of sleep quality affects the association is not well-understood. As revealed by the present study, when participants with a PSQI total score of > 5 were stratified by severity level, only those with very poor sleep quality were at significantly higher risk of obesity. This pattern suggests a potential dose-response relation, whereby greater severity of poor sleep quality is associated with an increasingly higher risk of incident obesity.

In addition to obesity, the present study revealed a significantly higher risk of diabetes at follow-up in participants who reported poor sleep quality at baseline. In a meta-analysis of risk factors for diabetes, overall poor sleep quality was associated with 50% higher risk of diabetes (Liu et al. 2025). As noted, studies included in the meta-analysis (Liu et al. 2025) were heterogenous in measuring sleep quality; self-reported sleep problems, subjective ratings on sleep quality, or a composite score from PSQI have been used in the definition of sleep quality. Interestingly, in the present study, when participants with poor sleep quality were further stratified by the PSQI total score as 6–10 or ≥ 11, it was found the association was only significant in those with a PSQI total score of 6–10. The lack of significant association in those with very poor sleep quality in this study may be because of the small sample size for this group while the effect size was also small.

There are various cross-sectional studies that examined sleep quality and prevalent metabolic syndrome, and meta-analyses of these studies reported an increased risk of metabolic syndrome when participants reported poor sleep quality (Hu et al. 2022; Lian et al. 2019). By contrast, very few longitudinal studies have examined associations between sleep quality and risk of metabolic syndrome, and there was a lack of significant association between sleep quality measured as the PSQI total score and incident metabolic syndrome (Bowman et al. 2019). While our results were consistent with this finding (Bowman et al. 2019), future studies are warranted to examine how different measures of sleep quality may affect the association.

The present study used subjective measures of sleep duration and sleep quality as assessed by the PSQI. Previous studies reported subjective measures of sleep are correlated with objective measures of sleep using actigraphy, although the agreement between the two measures could be poor (Miner et al. 2022; Scarlett et al. 2021). A meta-analysis of studies with objectively measured sleep duration revealed an increased risk of obesity in adults with short sleep duration (Jiang et al. 2024). Similarly, there were significant associations between actigraphy-based sleep duration and risk of diabetes (Albers et al. 2023), however, there was no significant association between objectively measured sleep duration and metabolic syndrome (Maghsoudipour et al. 2022). Taken together, these results, along with findings from other meta-analyses (Che et al. 2021; Hu et al. 2022; Jiang et al. 2024; Liu et al. 2025; Xie et al. 2021) indicate that associations between sleep and obesity, diabetes, or metabolic syndrome are relatively consistent, regardless of how sleep-related parameters are measured.

There are several strengths in the present study, such as availability of anthropometric and biometric data for objective assessment of study outcomes, relatively long follow-up, and assessment of both sleep duration and quality with multiple clinical outcomes. However, there are several limitations. First, the study used subjective measures of sleep duration and quality rather than objective measures of sleep, because only a small percentage of participants had the actigraphy data available in the study population. Second, there could be unmeasured confounders such as dietary intake or quality, which may affect the risk of chronic diseases. Moreover, medication

use and psychiatric conditions such as depression and anxiety were not included in the covariates. Instead, self-reported ratings of physical health and mental health were used, which could be more subjective than self-reported medication use or psychiatric conditions. Lastly, even with a longitudinal study design demonstrating a temporal relationship, findings from the present study cannot infer causal relationship.

In summary, poor sleep quality was associated with increased risk of developing obesity and diabetes in midlife. As part of a healthy lifestyle, maintaining a healthy sleep pattern may be a modifiable behaviour that may reduce the risk of these chronic conditions.

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