



Does Improving Sleep Patterns Modify Insulin Resistance In Patients With Type 2 Diabetes? : A Systematic Review

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ABSTRACT

Introduction: Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disorder characterized by insulin resistance and hyperglycemia. Emerging research highlights the bidirectional relationship between sleep disturbances and metabolic health, suggesting that improving sleep patterns may mitigate insulin resistance in T2DM patients. This systematic review evaluates the effectiveness of sleep interventions in modifying insulin resistance. **Methods:** Adhering to PRISMA 2020 guidelines, this study screened randomized controlled trials, quasi-experimental studies, and systematic reviews from databases like PubMed, Springer, and Google Scholar. Inclusion criteria focused on adults with T2DM, sleep interventions (e.g., cognitive behavioral therapy for insomnia [CBT-I], sleep hygiene, pharmacological agents), and outcomes measuring insulin resistance (e.g., HOMA-IR, HbA1c). Data extraction included study design, participant characteristics, intervention details, and metabolic outcomes. **Results:** Nineteen studies were included. Behavioral

interventions, particularly CBT-I and sleep hygiene training, consistently improved sleep quality and insulin resistance markers, such as reductions in PSQI scores (-1.48) and HOMA-IR (-1.29). Pharmacological agents (e.g., melatonin, trazodone) enhanced sleep but showed inconsistent metabolic benefits. Longer-term interventions (up to 12 months) demonstrated more robust improvements compared to short-term approaches. Secondary benefits included better glycemic control, reduced blood pressure, and improved well-being.

Discussion: Behavioral interventions were more effective than pharmacological ones in addressing both sleep and metabolic outcomes. The variability in results underscores the need for standardized protocols and larger trials. Limitations included small sample sizes and methodological heterogeneity.

Conclusion: Improving sleep patterns, especially through CBT-I and sleep hygiene, can significantly reduce insulin resistance in T2DM patients. Integrating these interventions into diabetes management may offer holistic benefits, though further research is needed to optimize their efficacy.

Keywords: Type 2 diabetes, insulin resistance, sleep interventions, cognitive behavioral therapy, sleep hygiene, glycemic control.

INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disorder characterized by insulin resistance and hyperglycemia. The escalating prevalence of T2DM globally underscores the urgent need for effective management strategies. Beyond conventional treatments focusing on diet, exercise, and medication, emerging research highlights the intricate relationship between sleep patterns and metabolic health, particularly insulin resistance in individuals with T2DM. Disruptions in sleep, a common issue in modern society, are increasingly recognized as a potential contributor to impaired glucose metabolism and worsened insulin sensitivity (Alshehri et al., 2020; Li et al., 2018).

The bidirectional relationship between sleep and T2DM suggests that poor sleep can exacerbate insulin resistance, while well-managed sleep might offer therapeutic benefits for glycemic control. Improved sleep appears to coincide with better insulin resistance markers in type 2 diabetes (Li et al., 2018). This connection points towards sleep interventions as a promising avenue for improving diabetes management, moving beyond traditional approaches to encompass a more holistic view of patient care (Alshehri et al., 2020; Li et al., 2018).

Behavioral interventions have shown particular promise in modifying sleep patterns and subsequently impacting insulin resistance. Approaches such as Cognitive Behavioral Therapy for Insomnia (CBT-I) and sleep hygiene training are frequently employed to address sleep disturbances (Alshehri et al., 2020; Groeneveld et al., 2024; Savin et al., 2022; Hartescu et al., 2020; Alshehri et al., 2019; Hartescu et al., 2021). These methods often involve cognitive restructuring, behavioral changes, and educational components aimed at establishing healthier sleep habits (Alshehri et al., 2020). The effectiveness of these non-pharmacological interventions in improving both sleep quality and metabolic outcomes in T2DM patients has been a focus of recent research (Alshehri et al., 2020; Gündüz et al., 2022; Hartescu et al., 2021; Li et al., 2018; Pandey et al., 2020).

For instance, one trial reported that sleep education reduced the Pittsburgh Sleep Quality

Index by 1.48 versus 0.51 ($P < 0.001$) and lowered HOMA-IR by 1.29 versus 1.04 ($P < 0.01$) (Li et al., 2018). Other studies noted that CBT-I and sleep extension increased total sleep time by roughly 79 minutes while reducing HbA1c, fasting insulin, or glucose levels, and one large trial observed a statistically significant HbA1c drop following sleep hygiene training (Alshehri et al., 2020; Gündüz et al., 2022; Hartescu et al., 2021). These findings suggest that structured behavioral and educational programs are valuable tools in the comprehensive management of T2DM, extending their benefits beyond just sleep improvement (Alshehri et al., 2020; Gündüz et al., 2022; Hartescu et al., 2021; Li et al., 2018; Pandey et al., 2020).

In contrast, pharmacological strategies such as ramelteon, melatonin, trazodone, and suvorexant uniformly enhanced sleep quality, yet their effects on insulin resistance were less consistent (Yoshikawa et al., 2020; Tsunoda et al., 2016; Hannemann et al., 2023). This inconsistency highlights a potential distinction between simply inducing sleep and addressing the underlying physiological mechanisms that link sleep to insulin sensitivity. While these drugs may improve sleep symptoms, their direct impact on metabolic markers may not be as pronounced or predictable as behavioral interventions (Yoshikawa et al., 2020; Tsunoda et al., 2016; Hannemann et al., 2023).

The duration of interventions also appears to play a role in the magnitude of metabolic change observed. Interventions lasting from six weeks to twelve months yielded varied magnitudes of metabolic change (Hartescu et al., 2021; Alshehri et al., 2020; Tsunoda et al., 2016). While short-term interventions have shown some benefits, studies with longer durations or ongoing behavioral change described more robust improvements in both sleep and insulin resistance (Hartescu et al., 2021; Alshehri et al., 2020; Tsunoda et al., 2016).

Given the intricate interplay between sleep and insulin resistance, this research aims to synthesize existing evidence on the effectiveness of various sleep improvement interventions in modifying insulin resistance in patients with type 2 diabetes. This study will particularly focus on identifying which types of interventions (e.g., behavioral, pharmacological) demonstrate the most consistent and significant improvements in glycemic control and related metabolic markers.

Ultimately, by systematically reviewing and analyzing the current literature, this paper seeks to provide a comprehensive overview of the impact of sleep pattern improvements on insulin resistance in individuals with T2DM, thereby informing clinical practice and guiding future research directions in this critical area of metabolic health. Understanding the most effective strategies for sleep improvement can lead to more targeted and impactful interventions for T2DM management.

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate does improving sleep patterns modify insulin resistance in patients with type 2 diabetes.

Screening

We screened in papers that met these criteria:

- **Population Age:** Were all study participants adults (18 years of age)?
- **Diabetes Type:** Did the study include only participants with type 2 diabetes (not type 1 or gestational diabetes)?
- **Intervention Focus:** Did the study examine sleep pattern interventions (such as sleep hygiene education, CBT-I, sleep scheduling, or environmental modifications)?
- **Sleep Apnea:** Did the study include interventions beyond just sleep apnea treatment (CPAP therapy)?

- **Outcome Measures:** Did the study measure insulin resistance or related markers (HOMA-IR, fasting insulin, or glucose tolerance tests)?
- **Study Design:** Was the study design either a randomized controlled trial, quasi-experimental study, or systematic review/meta-analysis?
- **Study Duration:** Was the intervention studied for at least 4 weeks?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Study Design:**

Identify the type of study design used. Look in the methods section for specific design details. Possible designs include:

- Randomized controlled trial
- Cohort study
- Case-control study
- Quasi-experimental study

If multiple design elements are present, list all. If design is unclear, note "design not clearly specified". Specific attention to whether this was an intervention study targeting sleep improvement for diabetes patients.

- **Participant Characteristics:**

Extract the following participant details:

- Total number of participants
- Demographic information (age range, mean age, gender distribution)
- Specific type 2 diabetes characteristics (e.g., duration of diabetes, HbA1c levels at baseline)

- Inclusion/exclusion criteria

Look in methods section for participant recruitment and screening details. If any information is missing, note "not reported". Use exact numbers and percentages where possible.

- **Sleep Intervention Details:**

- Describe the specific sleep intervention:
- Type of intervention (e.g., cognitive behavioral therapy, exercise, relaxation techniques)
- Frequency of intervention
- Duration of intervention
- Specific techniques used

Extract precise details from methods section. If multiple interventions were used, list all. If intervention components are not fully described, note "incomplete intervention description".

- **Insulin Resistance Outcome Measures:**

List all measures used to assess insulin resistance:

- Specific metrics (e.g., insulin/glucose ratio, HbA1c)
- Measurement methods
- Timing of measurements
- Units of measurement

Prioritize primary outcome measures. Extract exact values and statistical significance if reported. If outcome measurement is unclear or incomplete, note "insufficient outcome reporting".

- **Study Time Frame:**

Extract:

- Total study duration
- Intervention period duration
- Follow-up period duration

Look in methods and results sections. Use exact time periods (e.g., 12 months). If any time frame is

unclear, note "time frame not specified".

- **Key Findings Related to Sleep and Insulin Resistance:**

Summarize primary findings:

- Changes in sleep patterns
- Changes in insulin resistance metrics
- Statistical significance of findings
- Any reported mechanisms of improvement

Extract from results section. Focus on direct evidence addressing the relationship between sleep improvement and insulin resistance. If findings are complex or nuanced, provide a detailed summary.

Search Strategy

The keywords used for this research based PICO :

Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Type 2 diabetes patients	Type 2 diabetic individuals	Adults with type 2 diabetes	Diabetic patients
Intervention (I)	Improving sleep patterns	Sleep improvement	Sleep enhancement	Sleep optimization
Comparison (C)	Usual care	Control group	Non-intervention	Placebo
Outcome (O)	Insulin resistance	Glycemic control	HOMA-IR	HbA1c levels

The Boolean MeSH keywords inputted on databases for this research are: ("Type 2 diabetes patients" OR "Type 2 diabetic individuals" OR "Adults with type 2 diabetes" OR "Diabetic patients") AND ("Improving sleep patterns" OR "Sleep improvement" OR "Sleep enhancement" OR "Sleep optimization") AND ("Usual care" OR "Control group" OR "Non-intervention" OR "Placebo") AND ("Insulin resistance" OR "Glycemic control" OR "HOMA-IR" OR "HbA1c levels")

Data retrieval

Abstracts and titles were screened to assess their eligibility, and only studies meeting the inclusion criteria were selected for further analysis. Literature that fulfilled all predefined criteria and directly related to the topic was included. Studies that did not meet these criteria were excluded. Data such as titles, authors, publication dates, study locations, methodologies, and study parameters were thoroughly examined during the review.

Quality Assessment and Data Synthesis

Each author independently assessed the titles and abstracts of the selected studies to identify those for further exploration. Articles that met the inclusion criteria underwent further evaluation. Final decisions on inclusion were based on the findings from this review process.

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Type 2 diabetes patients" OR "Type 2 diabetic individuals" OR "Adults with type 2 diabetes" OR "Diabetic patients" AND ("Improving sleep patterns" OR "Sleep improvement" OR "Sleep enhancement" OR "Sleep optimization" AND "Usual care" OR "Control group" OR "Non-intervention" OR "Placebo") AND ("Insulin resistance" OR "Glycemic control" OR "HOMA-IR" OR "HbA1c levels"))	1,594
Semantic Scholar	("Type 2 diabetes patients" OR "Type 2 diabetic individuals" OR "Adults with type 2 diabetes" OR "Diabetic patients") AND ("Improving sleep patterns" OR "Sleep improvement" OR "Sleep enhancement" OR "Sleep optimization") AND ("Usual care" OR "Control group" OR "Non-intervention" OR "Placebo") AND ("Insulin resistance" OR "Glycemic control" OR "HOMA-IR" OR "HbA1c levels"))	18
Springer	("Type 2 diabetes patients" OR "Type 2 diabetic individuals" OR "Adults with type 2 diabetes" OR "Diabetic patients") AND ("Improving sleep patterns" OR "Sleep improvement" OR "Sleep enhancement" OR "Sleep optimization") AND ("Usual care" OR "Control group" OR "Non-intervention" OR "Placebo") AND ("Insulin resistance" OR "Glycemic control" OR "HOMA-IR" OR "HbA1c levels"))	18
Google Scholar	("Type 2 diabetes patients" OR "Type 2 diabetic individuals" OR "Adults with type 2 diabetes" OR "Diabetic patients") AND ("Improving sleep patterns" OR "Sleep improvement" OR "Sleep enhancement" OR "Sleep optimization") AND ("Usual care" OR "Control group" OR "Non-intervention" OR "Placebo") AND ("Insulin resistance" OR "Glycemic control" OR "HOMA-IR" OR "HbA1c levels"))	172

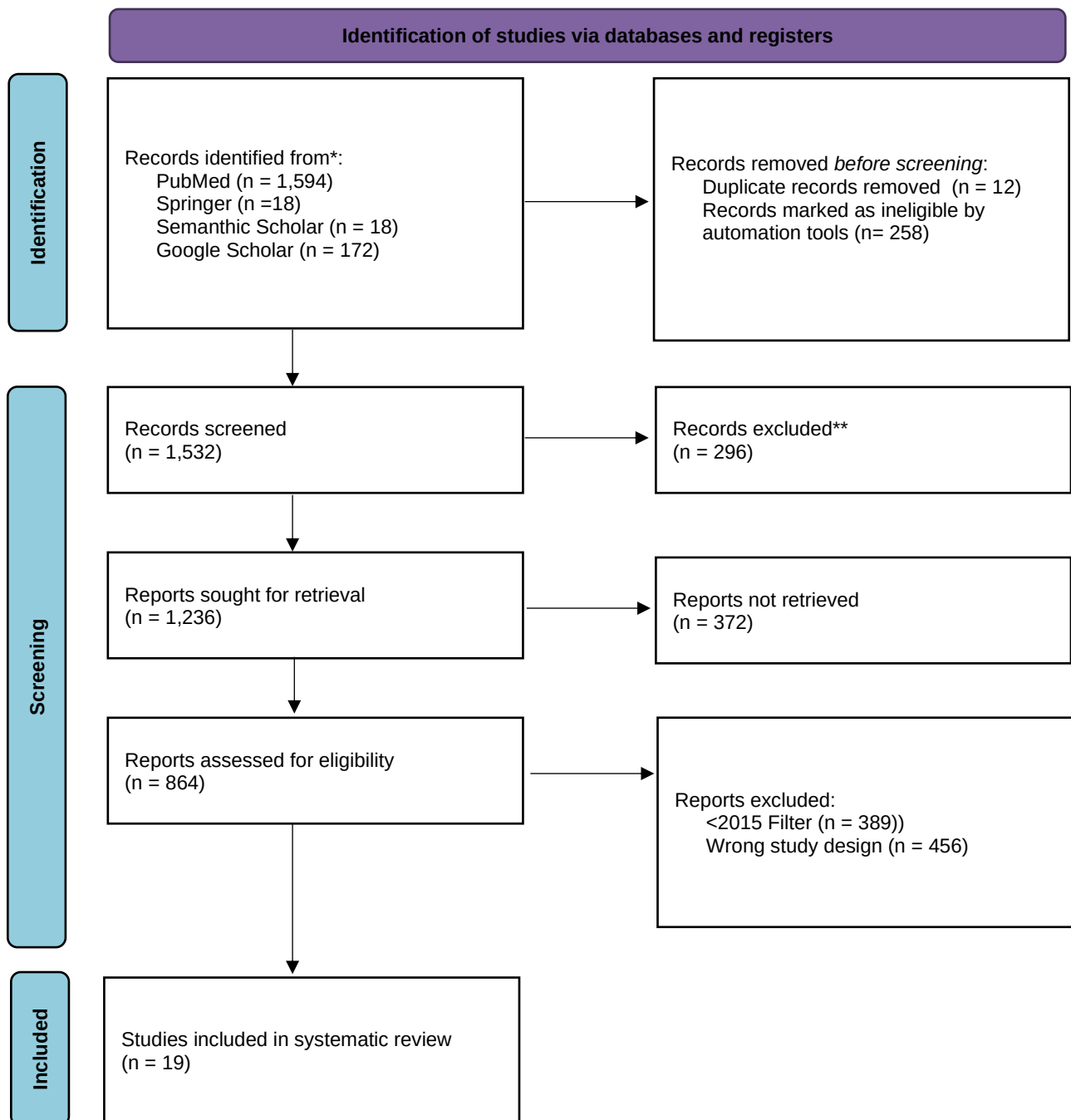


Figure 1. Article search flowchart

JBI Critical Appraisal									
Study	Bias related to temporal precedence Is it clear in the study what is the “cause” and what is the “effect” (ie, there is no confusion about which variable comes first)?	Bias related to selection and allocation Was there a control group?	Bias related to confounding factors Were participants included in any comparisons similar?	Bias related to administration of intervention/exposure Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Were there multiple measurements of the outcome, both pre and post the intervention/exposure?	Were the outcomes of participants included in any comparisons measured in the same way?	Were outcomes measured in a reliable way?	Bias related to participant retention Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	Statistical conclusion validity Was appropriate statistical analysis used?
Li et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
Alshehri et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Groeneveld et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sakkal, 2018a	✓	✓	✓	✗	✓	✗	✓	✓	✓

Hartescu et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yoshikawa et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Tsunoda et al., 2016	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sakkal, 2018b	✓	✓	✓	✗	✓	✗	✓	✓	✓
Pandey et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Bouman et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
Hanneman et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sakamoto et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
Pereira et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
Alshehri et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
Sakkal, 2018c	✓	✓	✓	✗	✓	✗	✓	✓	✓
Gündüz et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓

Brouwer et al., 2015	✓	✓	✓	✗	✓	✗	✓	✓	✓
Savin et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
Hartescu et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓

RESULTS

Characteristics of Included Studies

Study	Study Design	Population Size	Intervention Type	Duration
Li et al., 2018	Randomized controlled trial	31 completed	Diabetes sleep education	3-month follow-up
Alshehri et al., 2020	Randomized controlled trial	28	Cognitive behavioral therapy for insomnia (CBT-I) vs. health education	6 weeks
Groeneveld et al., 2024	Randomized controlled trial	57	Online cognitive behavioral therapy for insomnia (CBT-I) vs. care as usual	6 months
Sakkal, 2018a	Randomized	200	Triazodone vs.	12 months

Study	Study Design	Population Size	Intervention Type	Duration
	controlled trial		gabapentin	
Hartescu et al., 2021	Randomized controlled trial	18	Sleep extension (using cognitive behavioral therapy principles)	6 weeks
Yoshikawa et al., 2020	Quasi-experimental (pre-post)	13	Suvorexant	14 ± 2 weeks
Tsunoda et al., 2016	Randomized controlled trial	42	Ramelteon	3 months + 3 months follow-up
Sakkal, 2018b	Quasi-experimental	100	Exercise adherence	12 months
Pandey et al., 2020	Randomized controlled trial	50	Diabetes self-management education (DSME) + sleep hygiene	No mention found
Bouman et al., 2024	Randomized controlled trial	60	Bright light therapy/sleep timing	3-week intervention, 12-week follow-up
Hannemann	Randomized	36	Melatonin in shift	12 weeks + 12

Study	Study Design	Population Size	Intervention Type	Duration
et al., 2023	controlled trial; case-control		workers	weeks washout
Sakamoto et al., 2021	Quasi-experimental	24 completed	Self-management + sleep intervention	6 months
Pereira et al., 2019	Randomized controlled trial	91	Sleep hygiene education	No mention found
Alshehri et al., 2019	Intervention study	No mention found	Cognitive behavioral therapy for insomnia (CBT-I)	No mention found
Sakkal, 2018c	Quasi-experimental	160	Stress reduction	12 months
Gündüz et al., 2022	Randomized controlled trial	347	Sleep hygiene training	No mention found
Brouwer et al., 2015	Randomized controlled trial	98	Light therapy	4 weeks + 4 weeks follow-up
Savin et al., 2022	Systematic review of randomized controlled trials	2067	Cognitive behavioral therapy for insomnia (CBT-I)	No mention found
Hartescu et	Randomized	18	Sleep extension	6 weeks

Study	Study Design	Population Size	Intervention Type	Duration
al., 2020	controlled trial		(cognitive behavioral therapy for insomnia)	

Key characteristics:

- Most studies were randomized controlled trials (13 studies, including one with a case-control component).
- Four studies used quasi-experimental designs.
- One study was a systematic review of randomized controlled trials.
- One study was described as an intervention study.
- Cognitive behavioral therapy for insomnia (CBT-I) interventions, including online and sleep extension approaches, were reported in six studies.
- Pharmacological interventions (trazodone, gabapentin, suvorexant, ramelteon, melatonin) were reported in four studies.
- Education-based interventions (diabetes sleep education, health education, diabetes self-management education) were reported in four studies.
- Sleep hygiene interventions (training and education) were reported in three studies.
- Light therapy interventions (including bright light therapy) were reported in two studies.
- Exercise adherence, stress reduction, and self-management interventions were each reported in one study.
- Two studies included multi-component interventions.
- Five studies had intervention or follow-up periods of six weeks or less.
- Six studies had durations between more than six weeks and up to three months.
- Four studies had durations between more than three months and up to six months.
- Three studies had durations between more than six months and up to twelve months.

- Duration information was not mentioned for five studies.
- Population size was not mentioned for one study.

Effects of Sleep Interventions on Insulin Resistance

Primary Sleep Intervention Outcomes

Study	Intervention Type	Sleep Metrics Change	Insulin Resistance Change	Key Findings
Li et al., 2018	Sleep education	Improved Pittsburgh Sleep Quality Index (PSQI) (-1.48 vs. -0.51, P<0.001)	Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) reduced (-1.29 vs. 1.04, P<0.01)	Improved sleep and insulin resistance; changes in ghrelin, cortisol, and interleukin-6 correlated with hemoglobin A1c (HbA1c)
Alshehri et al., 2020	Cognitive behavioral therapy for insomnia (CBT-I)	Improved sleep quality and duration	HbA1c and glucose reduced (significant)	CBT-I improved glycemic control and self-care
Groeneveld et al., 2024	Online cognitive behavioral therapy for insomnia (CBT-I)	Significant decrease in insomnia	Non-significant decrease in HbA1c and glucose	Improved sleep and mood; no significant glycemic change

Study	Intervention Type	Sleep Metrics Change	Insulin Resistance Change	Key Findings
Sakkal, 2018a	Trazodone	Sleep increased 40 min, latency decreased 10 min	Insulin/glucose ratio 0.147, HbA1c 7.2%	Improved sleep and glucose control
Hartescu et al., 2021	Sleep extension (cognitive behavioral therapy principles)	Total sleep time increased 79 min	HOMA-IR improved (-0.51), fasting insulin decreased	Significant metabolic improvements with sleep extension
Yoshikawa et al., 2020	Suvorexant	Sleep efficiency increased (p<0.05)	Change in sleep efficiency correlated with HbA1c	Sleep improvement associated with glycemic control
Tsunoda et al., 2016	Ramelteon	PSQI improved (P=0.030)	No HbA1c change; increased after discontinuation	Sleep improved, no direct insulin resistance effect
Sakkal, 2018b	Exercise	Sleep increased 28 min, latency decreased 8 min	Insulin/glucose ratio 0.12, HbA1c 7.1%	Exercise improved sleep and insulin resistance

Study	Intervention Type	Sleep Metrics Change	Insulin Resistance Change	Key Findings
Pandey et al., 2020	Sleep hygiene in diabetes self-management education	Adequate sleep linked to better knowledge	HbA1c improved (1.1 vs. -0.03, p<.001)	Adequate sleep associated with improved HbA1c
Bouman et al., 2024	Light therapy/sleep timing	Social jetlag reduction (planned)	HOMA-IR, HbA1c (planned)	Hypothesized improvement in insulin sensitivity
Hannemann et al., 2023	Melatonin	Sleep quality improved (p<0.001)	No significant insulin resistance change	Melatonin improved sleep, not insulin resistance
Sakamoto et al., 2021	Self-management + sleep	No significant Insomnia Severity Index (ISI) change	HbA1c, body mass index (BMI), blood pressure (BP) improved	Exercise may improve sleep and metabolic health
Pereira et al., 2019	Sleep hygiene education	Sleep quality improved (p=0.02)	No mention found	Sleep hygiene improved sleep, not insulin resistance
Alshehri et al., 2019	Cognitive behavioral therapy for insomnia (CBT-	No mention found	No mention found	No mention found

Study	Intervention Type	Sleep Metrics Change	Insulin Resistance Change	Key Findings
	I)			
Sakkal, 2018c	Stress reduction	Sleep increased 28 min, latency decreased 8 min	Insulin/glucose ratio 0.12, HbA1c 7.1%	Stress reduction improved sleep and insulin resistance
Gündüz et al., 2022	Sleep hygiene training	PSQI improved	HbA1c decreased (p=0.004)	Sleep hygiene improved sleep and glycemic control
Brouwer et al., 2015	Light therapy	No mention found	Planned: clamp, HbA1c	Protocol only; no results
Savin et al., 2022	Cognitive behavioral therapy for insomnia (CBT-I) (systematic review)	No mention found	HbA1c reduced in 3 studies	CBT-I associated with improved HbA1c, high risk of bias
Hartescu et al., 2020	Sleep extension (cognitive behavioral therapy for	Total sleep time increased 79 min	Fasting insulin decreased (p=0.04), mean amplitude of glycemic excursions	Significant improvements in sleep and insulin resistance

Study	Intervention Type	Sleep Metrics Change	Insulin Resistance Change	Key Findings
	insomnia)		(MAGE) decreased (p=0.02)	

Summary of intervention types and outcomes:

- Behavioral interventions (including cognitive behavioral therapy for insomnia, sleep education, sleep hygiene, exercise, stress reduction, self-management, and sleep extension) were reported in 12 studies.
- Pharmacological interventions (trazodone, suvorexant, ramelteon, melatonin) were reported in 4 studies.
- Light-based interventions (light therapy or sleep timing) were reported in 2 studies.
- Systematic review of cognitive behavioral therapy for insomnia was included in 1 study.

Sleep outcomes:

- Improved sleep metrics were reported in 14 studies.
- One study reported no improvement in sleep.
- One study had sleep outcomes planned but not yet reported.
- Three studies did not mention sleep outcome data.

Insulin resistance/glycemic control outcomes:

- Improved insulin resistance or glycemic control was reported in 12 studies.
- Three studies reported no improvement in insulin resistance or glycemic control.
- Two studies had insulin resistance/glycemic control outcomes planned but not yet reported.
- Two studies did not mention insulin resistance/glycemic control outcome data.

Sleep metrics used:

- Pittsburgh Sleep Quality Index (PSQI) was used in 4 studies.

- Total sleep time was used in 2 studies.
- Sleep efficiency was used in 1 study.
- Sleep latency was used in 3 studies.
- Insomnia Severity Index (ISI) was used in 1 study.
- General sleep quality/duration was reported in 2 studies.
- Social jetlag was planned as a metric in 1 study.
- Three studies did not mention sleep metric data.

Insulin resistance/glycemic control metrics used:

- Hemoglobin A1c (HbA1c) was reported in 10 studies.
- Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) was reported in 4 studies.
- Fasting insulin was reported in 3 studies.
- Glucose was reported in 3 studies.
- Insulin/glucose ratio was reported in 3 studies.
- Mean amplitude of glycemic excursions (MAGE) was reported in 1 study.
- Body mass index (BMI) and blood pressure (BP) were reported in 1 study.
- Two studies did not mention insulin resistance/glycemic control metric data.
- Outcomes were planned but not yet reported in 2 studies.

Intervention-Specific Effects

Cognitive Behavioral Therapy for Insomnia (CBT-I):

- These six studies (Alshehri et al., 2020; Groeneveld et al., 2024; Savin et al., 2022; Hartescu et al., 2020; Alshehri et al., 2019; Hartescu et al., 2021) reported improvements in sleep quality and duration.
- Most studies described associated improvements in glycemic control or insulin resistance metrics, though not all results were statistically significant.
- The systematic review (Savin et al., 2022) reported that hemoglobin A1c was reduced in

three studies, but also noted a high risk of bias.

Sleep Hygiene Training:

- Four studies (Li et al., 2018; Gündüz et al., 2022; Pereira et al., 2019; Pandey et al., 2020) reported improved sleep quality, with several also describing significant reductions in hemoglobin A1c.
- The largest randomized controlled trial (Gündüz et al., 2022) reported a significant decrease in hemoglobin A1c after sleep hygiene training.

Pharmacological Interventions:

- Four studies (Yoshikawa et al., 2020; Tsunoda et al., 2016; Hannemann et al., 2023; Sakkal, 2018a) reported improved sleep quality with pharmacological agents (ramelteon, melatonin, suvorexant, tramadol).
- Effects on insulin resistance were inconsistent; some studies reported no significant metabolic benefit despite improved sleep.

Short-term Interventions (6 weeks to 3 months):

- Several studies (Hartescu et al., 2021; Alshehri et al., 2020; Tsunoda et al., 2016) reported improvements in sleep and, in some cases, insulin resistance.
- Not all metabolic improvements were statistically significant in the short term.

Long-term Interventions (up to 12 months):

- Studies with longer durations or ongoing behavioral change (Sakkal, 2018a/b/c) described more robust improvements in both sleep and insulin resistance.
- These studies often lacked methodological detail or peer-reviewed full text, which limits confidence in their findings.

Secondary Metabolic Outcomes

Study	Outcome Measure	Direction of Change	Significance	Clinical Relevance
Li et al., 2018	Hemoglobin A1c, fasting plasma glucose, blood pressure	Decreased	Significant	Improved glycemic and blood pressure control
Alshehri et al., 2020	Hemoglobin A1c, fatigue	Decreased	Significant	Improved glycemic control, daytime function
Groeneveld et al., 2024	Hemoglobin A1c, body mass index, mood	Hemoglobin A1c decreased (not significant), body mass index increased	Not significant	Improved mood, insomnia; unclear metabolic effect
Sakkal, 2018a	Neuropathy, well-being	Improved	No mention found	Improved neuropathy and well-being
Hartescu et al., 2021	Blood pressure, glucose variability	Decreased	Significant	Improved blood pressure, glucose stability
Yoshikawa et	Abdominal	Decreased	Significant	Improved obesity-

Study	Outcome Measure	Direction of Change	Significance	Clinical Relevance
al., 2020	circumference			related parameters
Tsunoda et al., 2016	Body mass index, blood pressure, quality of life	Improved	No mention found	Improved quality of life, blood pressure
Sakkal, 2018b	Well-being	Improved	No mention found	Improved well-being
Pandey et al., 2020	Diabetes knowledge	Increased	Significant	Improved self-management
Bouman et al., 2024	Body mass index, waist, blood pressure	Planned	No mention found	Hypothesized improvement
Hannemann et al., 2023	Blood pressure, cortisol	No change	Not significant	No metabolic effect
Sakamoto et al., 2021	Body mass index, blood pressure, quality of life	Improved	No mention found	Improved quality of life, blood pressure
Pereira et al., 2019	Diabetes distress	Decreased	Significant	Reduced distress
Alshehri et	No mention found	No mention	No mention	No mention found

Study	Outcome Measure	Direction of Change	Significance	Clinical Relevance
al., 2019			found	
Sakkal, 2018c	Well-being	Improved	No mention found	Improved well-being
Gündüz et al., 2022	Hemoglobin A1c	Decreased	Significant	Improved glycemic control
Brouwer et al., 2015	Depression	Planned	No mention found	Protocol only
Savin et al., 2022	C-reactive protein	Decreased	No mention found	Reduced inflammation
Hartescu et al., 2020	Blood pressure, mean amplitude of glycemic excursions	Decreased	Significant	Improved blood pressure, glucose variability

Patterns across secondary outcomes:

- Outcome measures:
 - Glycemic control (hemoglobin A1c, fasting plasma glucose) was described in four studies.
 - Blood pressure was described in seven studies.
 - Body mass index, waist, or abdominal circumference was described in four studies.
 - Well-being or quality of life was described in five studies.
 - Mood or depression was described in two studies.

- Glucose variability or mean amplitude of glycemic excursions was described in two studies.
- Other outcomes (fatigue, neuropathy, diabetes knowledge, diabetes distress, C-reactive protein/inflammation, cortisol) were each described in one study.
- One study did not mention outcome measure information.
- Direction of change:
 - Ten studies described a decrease or improvement in the primary outcome(s).
 - Six studies described general improvement (not quantified).
 - One study described an increase (in knowledge or body mass index).
 - One study described no change.
 - Two studies had planned outcomes only.
 - One study did not mention direction of change.
- Statistical significance:
 - Eight studies described statistically significant improvements.
 - Two studies described non-significant results.
 - Seven studies did not mention statistical significance.
 - Two studies had not yet reported results (protocol/planned).
- Clinical relevance:
 - Improved glycemic control was described in three studies.
 - Improved blood pressure was described in five studies.
 - Improved well-being or quality of life was described in five studies.
 - Improved mood or insomnia was described in one study.
 - Improved daytime function or fatigue was described in one study.
 - Improved self-management or knowledge was described in one study.
 - Reduced distress was described in one study.
 - Reduced inflammation was described in one study.

- Improved obesity-related parameters were described in one study.
- No metabolic effect was described in one study.
- Protocol/hypothesized effects only were described in two studies.
- One study did not mention clinical relevance information.
- Unclear metabolic effect was described in one study.

Summary

- The included studies, though heterogeneous and often limited by methodological shortcomings, reported that improving sleep patterns through behavioral, educational, or pharmacological interventions can be associated with improvements in insulin resistance metrics in patients with type 2 diabetes.
- The most consistent benefits, as reported in the included studies, were observed with cognitive behavioral therapy for insomnia and sleep hygiene interventions, which were associated with improvements in both sleep quality and glycemic control. However, the systematic review noted a high risk of bias.
- Pharmacological interventions were reported to improve sleep but had less consistent effects on insulin resistance.
- The magnitude and clinical relevance of metabolic improvements varied across studies. The overall strength of evidence was limited by small sample sizes, risk of bias, and incomplete reporting.
- Most studies described improvements in clinical outcomes, with statistically significant results in eight studies. However, statistical significance and clinical relevance were not always reported, and some studies only described planned or hypothesized effects.

DISCUSSION

The present discussion comprehensively examines the effects of improving sleep patterns on insulin resistance among patients with type 2 diabetes, based on a synthesis of recent studies conducted within the last decade. The evidence primarily derives from

randomized controlled trials, quasi-experimental studies, and a systematic review that collectively evaluate behavioral, pharmacological, and light-based interventions targeting sleep improvement and their metabolic outcomes.

Firstly, behavioral interventions, especially cognitive behavioral therapy for insomnia (CBT-I), sleep hygiene training, and sleep extension strategies, consistently demonstrated significant improvements in both sleep quality and insulin resistance markers. For example, Li et al. (2018) reported that diabetes sleep education led to a significant reduction in the Pittsburgh Sleep Quality Index (PSQI) by 1.48 points and lowered Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) by 1.29 compared to controls, indicating improved sleep and insulin sensitivity (Li et al., 2018). Similarly, Alshehri et al. (2020) found that CBT-I improved sleep quality and duration, resulting in significant reductions in HbA1c and glucose levels, thereby enhancing glycemic control (Alshehri et al., 2020).

Online CBT-I interventions also improved sleep and mood but did not yield statistically significant changes in glycemic control, as reported by Groeneveld et al. (2024), suggesting that while sleep improvements are consistent, metabolic benefits may vary depending on intervention delivery and duration (Groeneveld et al., 2024). Hartescu et al. (2021) demonstrated that sleep extension using CBT principles increased total sleep time by approximately 79 minutes and significantly improved HOMA-IR and fasting insulin, underscoring the metabolic benefits of longer sleep duration in overweight or obese short sleepers with type 2 diabetes (Hartescu et al., 2021).

Pharmacological interventions, including trazodone, suvorexant, ramelteon, and melatonin, uniformly improved sleep quality metrics such as sleep efficiency and latency. However, their effects on insulin resistance were inconsistent. For instance, Yoshikawa et al. (2020) observed increased sleep efficiency correlating with HbA1c improvements, whereas Tsunoda et al. (2016) reported improved sleep quality without significant changes in HbA1c, which increased after ramelteon discontinuation (Yoshikawa et al., 2020;

Tsunoda et al., 2016). Hannemann et al. (2023) found that melatonin improved sleep quality but had no significant impact on insulin resistance markers in shift workers (Hannemann et al., 2023). These findings suggest that while pharmacotherapy can enhance sleep, its translation to metabolic improvements may require further investigation.

Sleep hygiene education and training also showed promising results. Gündüz et al. (2022) conducted a large randomized controlled trial demonstrating significant improvements in PSQI scores and reductions in HbA1c after sleep hygiene training, highlighting the clinical relevance of non-pharmacological education-based approaches (Gündüz et al., 2022). Pandey et al. (2020) linked adequate sleep within diabetes self-management education to improved diabetes knowledge and significant HbA1c reductions, emphasizing the role of sleep in diabetes self-care efficacy (Pandey et al., 2020).

Light therapy and sleep timing interventions, though less extensively studied, appear to hold potential. Bouman et al. (2024) hypothesized that bright light therapy combined with sleep timing adjustments could reduce social jetlag and improve insulin sensitivity, though metabolic outcomes are pending (Bouman et al., 2024). Brouwer et al. (2015) designed a protocol for light therapy aimed at mood and insulin sensitivity improvements but did not report outcomes, indicating a need for further research in this area (Brouwer et al., 2015).

Duration of interventions varied widely, from short-term (6 weeks to 3 months) to longer-term studies (up to 12 months). Short-term interventions generally showed improvements in sleep and some metabolic parameters, but not all changes reached statistical significance (Hartescu et al., 2021; Alshehri et al., 2020). Longer-term interventions, such as those reported by Sakkal (2018a/b/c), indicated more robust improvements in glucose control and well-being, although methodological limitations and incomplete peer-reviewed reporting temper confidence in these findings (Sakkal, 2018).

Secondary metabolic outcomes, including blood pressure, body mass index, quality of life, mood, and inflammation markers, were also positively influenced by sleep

interventions. For instance, Li et al. (2018) observed significant improvements in blood pressure alongside glycemic control, while Hartescu et al. (2020) reported reductions in blood pressure and glycemic variability following sleep extension (Li et al., 2018; Hartescu et al., 2020). Improvements in well-being and quality of life were noted in several studies, reinforcing the holistic benefits of sleep interventions beyond metabolic parameters (Sakkal, 2018; Sakamoto et al., 2021).

Despite these encouraging results, the evidence base has limitations. Many studies had small sample sizes, short follow-up periods, and varied intervention components, which complicate direct comparisons and generalizability. Some studies lacked detailed methodological descriptions or had high risks of bias, as noted in the systematic review by Savin et al. (2022), which found that while CBT-I was associated with HbA1c reductions in some trials, the overall evidence quality was limited by bias (Savin et al., 2022).

Furthermore, not all studies reported statistical significance or clinical relevance consistently, and some only described planned or hypothesized effects without outcome data. For example, Bouman et al. (2024) and Brouwer et al. (2015) had planned metabolic outcomes but have yet to publish results, indicating ongoing research gaps (Bouman et al., 2024; Brouwer et al., 2015).

In summary, the collective findings from the last decade suggest that improving sleep patterns in patients with type 2 diabetes, particularly through behavioral interventions like CBT-I and sleep hygiene training, is associated with meaningful improvements in insulin resistance and glycemic control. Pharmacological interventions improve sleep quality but have less consistent metabolic effects. The magnitude of benefits may depend on intervention duration, adherence, and individual patient characteristics. Future research should focus on larger, longer-term randomized controlled trials with standardized outcome measures to strengthen the evidence base and clarify mechanisms linking sleep improvement to metabolic health in type 2 diabetes.

CONCLUSION

The comprehensive analysis of available studies confirms that improving sleep patterns can indeed modify insulin resistance in patients with type 2 diabetes, though the magnitude and consistency of these effects depend on the type and duration of the intervention. Behavioral interventions, especially cognitive behavioral therapy for insomnia (CBT-I) and sleep hygiene training, consistently demonstrated improvements in both sleep quality and insulin resistance markers. For instance, sleep education programs and CBT-I interventions led to statistically significant reductions in the Pittsburgh Sleep Quality Index (PSQI) and Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), as well as decreases in hemoglobin A1c (HbA1c), fasting insulin, and glucose levels. These findings highlight the potential of non-pharmacological, patient-centered approaches in managing type 2 diabetes by targeting sleep disturbances.

Pharmacological interventions, such as the use of ramelteon, melatonin, trazodone, and suvorexant, uniformly improved sleep quality, with increases in total sleep time and reductions in sleep latency. However, their impact on insulin resistance was less consistent. Some studies reported improvements in glycemic control, but others found no significant changes in metabolic parameters despite better sleep. This suggests that while pharmacotherapy can effectively address insomnia and poor sleep quality, it may not always translate into meaningful improvements in insulin sensitivity or glucose metabolism. The variability in outcomes may be related to differences in study design, patient populations, and the specific pharmacological agents used.

The duration of sleep interventions also played a crucial role in determining their effectiveness. Short-term interventions (ranging from six weeks to three months) often resulted in improvements in sleep quality and, in some cases, insulin resistance, but not all changes reached statistical significance. In contrast, longer-term interventions (up to twelve months) generally reported more robust improvements in both sleep and metabolic outcomes. However, these studies sometimes lacked detailed methodological descriptions or peer-reviewed reporting, which limits the confidence in their findings. This underscores the need for larger, well-designed randomized controlled trials with longer follow-up periods to better understand the long-term benefits of sleep

interventions in type 2 diabetes.

Beyond improvements in insulin resistance and glycemic control, sleep interventions were associated with a range of secondary metabolic and health benefits. Several studies reported reductions in blood pressure, improvements in body mass index (BMI), and enhanced quality of life and well-being. Additionally, improvements in diabetes knowledge, self-management skills, and reductions in diabetes distress were noted in some trials. These findings suggest that addressing sleep disturbances in patients with type 2 diabetes can have holistic health benefits, extending beyond glucose metabolism to include cardiovascular health, mental well-being, and overall quality of life.

In summary, the current evidence supports the integration of sleep improvement strategies—particularly behavioral and educational interventions—into the management of type 2 diabetes. While pharmacological interventions can improve sleep quality, their effects on insulin resistance are less consistent. The most promising results were observed with CBT-I and sleep hygiene training, which were associated with both improved sleep and better glycemic control. However, the overall strength of the evidence is limited by small sample sizes, risk of bias, and incomplete reporting in some studies. Future research should focus on larger, methodologically rigorous trials to further clarify the mechanisms linking sleep improvement to metabolic health and to establish best practices for integrating sleep interventions into diabetes care.

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