The association of meal glycemic index/load with quantitative and qualitative indicators of sleep: a systematic review

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DOI 10.23736/S0026-4806.21.07444-9
ISSN 0026-4806
ESSN 1827-1669

Publisher: Edizioni Minerva Medica

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ABSTRACT

INTRODUCTION: We sought to systematically review the association between meal glycemic index (GI) or glycemic load (GL) and quantitative sleep indicators.

EVIDENCE ACQUISITION: PubMed, Scopus, Web of Science, and Embase were searched up to March 2021. Both observational and clinical trials studies, with both male and female participants of all ages, were included.

EVIDENCE SYNTHESIS: A total of 10 studies were included in this review; six with clinical trial (CT) and four with cross-sectional design. Among the six CT, three studies indicated a significant effect of HGI on sleep (two in young male athletes (n=8 & 9) and one in adults (n=8)), while three others failed to detect any significant effect (young males (n=12), children (n=8), toddlers (n= 56)). Among the cross-sectional studies, HGI meals were associated with improved sleep duration or quality in two studies (594 toddlers and 1848 adults), however, contrastingly, were also associated with sleep disturbances (108 students and 53069 postmenopausal women). CONCLUSIONS: HGI meals likely improve sleep onset latency in young males. For other indicators of sleep quality and other population groups, the results are equivocal. Most of the available studies were conducted in special population groups and were inadequately designed; whilst CT were of short duration and small sample sizes. Therefore, further well-designed clinical trials are required before further definitive conclusions can be made.

Keywords: Glycemic index, Glycemic load, Insomnia, Sleep quality, Systematic review

Introduction

Both nutrition and sleep play a pivotal role in human health and well-being. Based on the available evidence, a bidirectional and complex relationship exists between sleep and nutrition. Indeed, diet and nutrition can influence the duration and quality of sleep [9, 10]. Contrastingly, poor sleep is correlated with the overeating, obesity, and diabetes, among other non-communicable diseases [11]. Sleep restriction can lead to a change in ghrelin and leptin levels, which in turn increases hunger and calorie intake [12-14]. Additionally, reductions in physical activity could occur in response to fatigue related to the poor sleep [15]. Based on the extant literature, insufficient sleep can lead to a decrement in insulin sensitivity and acute insulin response to intravenous glucose, and an increment in the HOMA [16, 17]. Moreover, it has been shown that increased insulin release may be unable to compensate for insulin sensitivity decrements caused by insufficient sleep [18].

Among the studies that have explored the effect of nutrition on sleep, some have focused on certain foods and drinks, while others have assessed dietary pattern, and the micronutrient and macronutrient content of diets [19, 20]. Carbohydrate (CHO) is a macronutrient regarded as the main source of our energy requirement, where both content and type of CHO could affect sleep [21, 22]. Results of studies that have assessed the association between carbohydrate intakes and sleep quality are conflicted, which may be attributable to carbohydrate quality [23].

Insulin plays a key role in the suggested mechanism for the effect of CHO or glycemic index (GI) on sleep [24]; whilst tryptophan, as a precursor of serotonin and melatonin, has a direct effect on sleep owing to the regulation of circadian rhythms [25]. Tryptophan brain uptake is not only related

to its blood concentration, but is also influenced by other LNAA (large neutral amino acids) concentrations, due to their competition for the same blood brain transporter [26]. Since insulin increases amino acids uptake, the change in TRP/LNAA ratio causes greater uptake of tryptophan by the brain [24]. Herrera et al. indicated that maintaining the amount of CHO caused the TRP/LNAA ratio to be 17% in the HGI group and 8% in the LGI group. Thus, it seems that higher postprandial insulin after HGI meal consumption may be the feature that ameliorates sleep indices.

One approach for categorizing CHO by type is the meal GI, which is a numeric physiological cornerstone [27], and regarded as an evaluation of the quality of CHO [27]. Indeed, consideration of different glycemic responses after consumption of various CHO-containing foods, with similar macronutrients, led to the definition and creation of this classification [28]. GI is calculated by measuring the blood glucose response after consuming 50 grams of available CHO from a specific food and comparing it with the same amount of glucose or white bread [29]. If the area under the blood glucose response curve of the food was smaller than glucose, the food is regarded as low GI (LGI) [28]. The numerical classification may be demarcated as: LGI: $\leq$55, medium GI: 56 to 69, high GI: $\geq$70 [30]. Although some studies have examined the effects of consumption of different GI meals on sleep quality, an overarching review has not yet been conducted. Therefore, we designed the current systematic review to, i) summarize the results of the existing literature, ii) discuss the potential explanations for the obtained results, and iii) highlight the gaps to be addressed in future studies.

Evidence acquisition

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [31] was adhered to in conducting this systematic review.

Study selection criteria

Type of studies

Clinical trial studies that investigated the effect of glycemic index/load on sleep quality and quantity, and observational studies (cross-sectional, case control and cohort) that assessed the association between glycemic index/load and sleep quality and quantity, were included in this systematic review.

Type of participants

Both male and female healthy subjects of any age were included.

Search strategy

PubMed, Scopus, Web of Science, and Embase were searched from database inception up to March 2021. Moreover, bibliographies of reviews and primary studies were scanned for additional relevant articles. The search strategy was as follows: ("Disorders of Initiating and Maintaining Sleep" OR DIMS OR Awakening OR Sleep OR Sleeplessness OR Insomnia OR "sleep disorder" OR "sleep disturbance" OR "chronic sleep problem" OR "sleep problem" OR "poor sleep" OR "chronic Insomnia" OR "insomnia*" OR "sleep complaint" OR "sleep quality") AND ("Glycemic Indices" OR "Glycemic Index" OR (Load AND Glycemic) OR "Glycemic Load") OR "glycaemic

index" OR "glycaemic load". Two reviewers (AK, NS) independently screened eligibility of studies, and any discrepancies were resolved by discussion.

Risk of bias (quality) assessment

The quality of cross-sectional studies was assessed using the Newcastle Ottawa scale; Three main domains, including "selection", "comparability", and "outcome" were examined to rate the quality in this scale. In the "selection" domain, four items were assessed (representativeness of the exposed cohort, selection of the non-exposed cohort, ascertainment of exposure, and demonstration that the outcomes were not present at the start of the study). In the "comparability" domain, the control of confounders in the design or analysis of the studies was checked. Finally, in the "outcome" domain, the outcomes ascertainment, duration of follow-up and adequacy of follow-up of cohorts were considered. If a study received a score of 3–4 in the "selection" domain, 1-2 in the "comparability" domain, and 2–3 in the "outcome" domain, the quality was rated as good; a score of 2 in the "selection" domain and 1–2 in the "comparability" domain and 2–3 in the "outcome" domain, the quality was rated as fair, and for a score of 0–1 in the "selection" domain or 0 in the "comparability" domain or 0–1 in the "outcome" domain, the quality was rated as poor. The quality of clinical trial studies was assessed using Cochrane Risk of Bias Tool for Randomized Controlled Trials. Studies were assessed for five criteria, including; random sequence generation, allocation concealment, blinding of participants, personnel and outcome assessment, incomplete outcome data, selective reporting. In cases where all criteria were met, or only one criterion was scored as unclear, the quality was judged as good; one criterion not met or two criteria unclear was scored as fair quality, and two or more criteria not met or more than two unclear was regarded as poor quality.

Evidence synthesis

The initial search yielded 403 records; of these, 151 articles were duplicates, so were excluded. We further excluded 241 studies after reviewing the titles and abstracts of the papers as they were irrelevant to the present study or were review papers; therefore, 11 articles remained for full text assessment. Of these, one was excluded due to the lack of data accessibility [32]. Accordingly, 10 studies, including 2 conference papers and 8 journal articles, were included in the current systematic review. Among the reviewed articles, 6 were of clinical trial design and 4 cross-sectional. The sample size of studies ranged from 8 to 56 in clinical trial studies, and 108 to 53069 in cross-sectional studies. The characteristics of studies have been summarized in Table I (cross-sectional studies) and Table II (trial studies).

Study Population and methods

Cross-Sectional studies

The participants in one study were toddlers, aged between 1.5 to 2 years [33], two studies recruited adults [34, 35], and the fourth study recruited postmenopausal women [36]. Food intake was deduced from a self-administered diet history questionnaire, food record, or FFQ. The GI was obtained by using the available nutritional tables or calculating for each food.

Different questionnaires, such as the Pittsburgh Sleep Quality Index (PSQI), Women's Health Initiative Insomnia Rating Scale (WHIIRS), and a reporting questionnaire were applied to assess sleep quality.

Trial studies

Four studies were conducted in adults, one in children aged between 8 to 12 years, and one in toddlers. Among the studies in adults, in three studies the participants were male while one study included both males and females. Among the studies in males, the participants in two studies were

athletes and healthy individuals, respectively. Sleep parameters were recorded by Polysomnography (PSG) in 4 studies, whilst the two other studies used actigraphy and a composition of actigraphy and sleep questionnaires, respectively.

Meal GI and sleep quality

Cross-sectional studies

Diethelm et al. [33] explored the association between the nutritional composition of evening meals and toddlers sleep, and assessed 594 children aged between 1.5 to 2 years. Food intake was assessed with the help of parents by weighing and recording food and beverages over three days. Sleep data were obtained by the results of pediatrician questioning in each visit: "How many hours does your child usually sleep per 24 h?". The researchers assessed sleep problems, nighty eating, and daily sleep duration of participants, and the results suggested that a longer sleep duration was significantly associated with higher energy intakes from the evening meal, especially from HGI foods.

In Yoneyama et al., the consequences of three regular starchy foods intake with different GI on sleep quality were assessed [34]. Rice, bread, and noodle consumption and sleep quality were evaluated in 1,848 men and women. A self-administered diet history questionnaire, which included 147 foods and beverages, was applied to evaluate the dietary habits of the previous month. The Japanese version of the PSQI questionnaire was utilized to estimate sleep quality in the preceding month. No association was observed between bread intake and sleep quality, while noodle consumption was correlated with poor sleep quality; furthermore, better conventional sleep was observed after higher dietary GI and high rice consumption.

Kuo et al [35] assessed the effect of meal GI and the time of meal intake on sleep quality in a group of medical college students. Sleep was assessed by PSQI, and meal content and time of eating was recorded using a mobile application (LINE app). The researchers found that in the group with a low GI diet, the sleep duration was longer than the group with high GI; where the latter group reported greater sleep problem at awakening.

Gangwisch et al. [18] conducted research on postmenopausal women who participated in the Women's Health Initiative Observational Study. In this investigation, a 145-item FFQ was applied to evaluate dietary intake, whilst data pertaining to insomnia was obtained using a validated five-item questionnaire. The study revealed that a diet with high GI, such as consumption of dietary added sugars, starch, and refined grains, could increase the prevalence and incidence of insomnia. The aforementioned results have been summarized in Table 3.

Trial studies

Sleep quality, in terms of Total sleep time (TST), Sleep efficiency (SE), and Sleep onset latency (SOL), was evaluated in all of the studies, while the sleep macrostructure was assessed only in 3 studies. Overall, all of the trials evaluated the short-term effects of meals with different GI on sleep.

Afaghi et al. [37] conducted a research on young healthy males with normal weight, who had no history of significant medical, psychiatric, or sleep disorders, sedatives, antidepressants, or recreational drugs intake, regularly not intaking more than 20 g alcohol, and refrained from strenuous exercise a day before the study. The authors reported a statistically significant decrease in SOL after consumption of high GI (HGI) meal in comparison to LGI, where the meals were a combination of steamed rice and vegetables with a GI of 50 and 109. Moreover, results indicated

that the time of eating the high-GI meal was also an independent factor influencing the SOL, where consumption of a HGI meal 4 hours before bedtime led to a more significant reduction on SOL in comparison to having the same meal an hour before bedtime.

Herrera et al.[38] assessed the effect of HGI vs LGI isocaloric meal, consumed 3 hours before subjects' habitual bedtime, on sleep quality among 4 women and 4 men. Subjects reported feeling more rested after consuming HGI meal vs. LGI, and the researchers concluded that symptoms of insomnia could be ameliorated after consuming a HGI meal, especially in women. However, PSG indices were not different between the 2 groups.

Jalilolghadr et al. [39] compared the effect of high vs. low GI milk consumption on eight children's sleep patterns, one hour before sleep, in 3 consecutive nights. Results indicated that the participants who consumed HGI drinks had higher non-rapid eye-movement (NREM) percentage and higher total arousal index in comparison to the LGI drink group. Whilst Misra et al [40], in a double-blind randomized controlled trial, examined the impact of 3.5 days' milk consumption with differing glycemic properties (Low = 23 and High = 65) on the sleep patterns of toddlers, aged 14–24 months. Accordingly, no significant difference was observed between the groups after the period of intervention.

Vlahoyiannis et al. [41] evaluated the effect of different GI meals consumed after exercise on sleep indices and on the next day exercise performance in a group of athletes. The study demonstrated that only consumption of a HGI meal elicited a significant improvement in sleep indices. In another study on athletes, the effect of HGI vs. LGI meals consumption (dinner and evening snack) on sleep quality was investigated in nine Brazilian basketball-playing adult males [42]. The authors assessed daytime sleepiness during the investigation, and participants received evening meals with the same GI that consumed during the dinner. It was found that GI did not

influence sleep parameters; however, daily energy intake was negatively correlated with TST, and positively with wake after sleep onset (WASO). Moreover, the authors reported an excessive daytime sleepiness, which could be related to the competition condition. Overall, the results of this study suggested that the food consumed during the day had a greater impact on sleep parameters. The aforementioned results have been summarized in Table IV.

Quality of studies

Among the observational studies, two had a good and one had a fair quality. All of the clinical trials had a poor quality, based on the "Cochrane's quality assessment tools"; where randomization and blindness were the prevalent sources of bias in the studies. Results of quality assessment have been summarized in Table V for the observational studies and Table VI for the clinical trials. Moreover, some of the studies have strengths or limitations other than the criteria considered in quality assessment tool that have been summarize in Table VII for some of the studies.

Discussion

The role of CHO in improving sleep was first evaluated in 1981 and promising results were observed [43]. Indeed, contemporary evidence suggests that higher consumption of CHO can increase daily drowsiness [42, 44]; however, it is not yet established if the effect on sleep is mediated by the "quality" or "quantity" of CHO load. While some studies have indicated that type of CHO, measured with GI, has a greater impact on sleep quality than CHO quantity [23], others suggested that sleep patterns are influenced by the energy received from food, independently from GI [42]. To address this equivocality, we conducted the current study. Accordingly, our systematic review indicates that there is no consensus among the studies on the effect GI on total sleep duration and other sleep parameters

Generally, three clinical trials indicated a significant effect of HGI on sleep duration and quality; two were conducted in young male athletes (n=8 & 9), and one in adults (n=8). Among them, one study was conference paper so we did not have access to details about the sleep parameters. In two other studies, sleep duration and sleep onset latency were improved, sleep efficiency was improved in one, while in the other study, it remained unchanged.

The other three clinical trials failed to detect any significant effect; the participants in these studies were young males (n=12), children (n=8), and toddlers (n= 56), respectively. In all three studies, sleep duration and sleep efficiency were unchanged, while sleep onset latency improved in one study. However, these results should be interpreted cautiously, largely owing to the small sample sizes

An important factor that can influence the results is the age of participants. Indeed, in the studies reporting a positive effect, the age range of participants was approximately the same; while in studies with insignificant results, the age group of participants varies from toddlers to adults aged 18-35 years. Furthermore, sleep latency inset was improved in all four studies on adult participants (mostly young males), which suggests that a HGI meal may improve SOL in young adults. Another probable influencing factor is the time interval between meal intake and bedtime, where eating near bedtime may increase the prevalence of sleep disorders. In Afaghi et al., consumption of HGI food 4 hours before sleep, compared to 1 hour, improved LOS significantly more. In Jalilolghadr et al. [39], a HGI meal consumed 1 hour before bedtime had no effect any the sleep indices. the remaining studies did not report the time interval; accordingly, future studies should consider this issue in the study design, and report appropriately.

Among the cross-sectional studies, a HGI meal was associated with improved sleep duration or quality in two studies (594 toddlers and 1848 adults), yet, inconsistently, in two other studies, HGI

was associated with sleep disturbances (108 students and 53069 postmenopausal women). We retained three studies conducted on toddlers and children; two with clinical trial design and one with cross-sectional design. In the cross-sectional study, the results in toddlers were discordant with the results of clinical trials on toddler and children. Indeed, due to the dearth of studies, it cannot be determined whether HGI is effective in toddlers and children. Although some studies reported positive or null associations, two studies found an inverse relationship. One explanation for the conflicting results may be due to the participants characteristics, where one of the studies reporting an inverse relationship recruited postmenopausal women Indeed, in this study, although glucose control parameters were not reported, because of their postmenopausal status; being overweight and old age (≈63.5 yr), are known contributors to insulin resistance, which may adversely impact sleep indices. In a study of people with type 2 diabetes, it was found that those with higher blood glucose levels experienced poorer sleep [46].Indeed, insulin has a key role in the putative mechanism for the effect of HGI meals on sleep, where insulin increases the LNAA amino acids uptake, in-turn, increasing the uptake of tryptophan by the brain. However, in insulin resistance, this process is dysfunctional. In addition, the potential causes of sleep disorders in menopause are abundant, including change in reproductive hormone levels, circadian rhythm abnormalities, mood disorders, coexistent medical conditions, and lifestyle factors. Additionally, other common sleep problems in this age group, such as obstructive sleep apnea and restless leg syndrome, can also worsen the sleep quality [47].

Perspectives and applications

Most of the retained studies in the current review did not account for differences in BMI, pubertal/fertility status, social jet lag, presence of respiratory disorder, particularly sleep apnea,

and presence of excessive daytime sleepiness. Moreover, most of the included studies did not consider the changes in diet composition, as well as the changes in the time of consumption, which may have caused or exacerbated sleep disorders. For instance, higher CHO may induce an increase in minute ventilation (due to increasing load of carbon dioxide) [55], that, in turn, predisposes an individual to an increased respiratory control loop gain, a condition that is associated with obstructive sleep apnea [56]. It is advocated that future studies take alcohol consumption into consideration, due to its' impact on upper airways resistance , apneas, and hypopneas [57]. Furthermore, a final consideration is that, for the accurate assessment of GI or GL of a meal before sleep, the diet of both the intervention and control group should be identical and only the GI should be divergent; this would contribute to the veracity of findings.

Conclusion

Our results suggest that a HGI meal likely contributes to an improved sleep onset latency in young males. For other indicators of sleep quality and other population groups, results are inconsistent. Indeed, most of the included studies were conducted in special population groups and were not appropriately designed, whilst clinical trials were of short duration and recruited small sample sizes. To provide more definitive conclusions, further well-designed clinical trials are required; moreover, the timing of meals before sleep may be an important factor, and thus the optimal time interval should be elucidated.

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Conflicts of interest.— The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.— AK designed the research; AK and NS assessed study eligibility and conducted quality assessments, data extraction, and data reporting; EA interpreted the results; EA and NS drafted the initial manuscript under the supervision of AK. FF critical revision of the manuscript. All authors read and approved the final version of the manuscript; AK and NS guarantors for the study.

Table I.— *Summary of cross-sectional studies assessed the relationship between meal GI and sleep quality.*

Study	Country	Participant characteristics	Sample size	Age	Dietary evaluations method	Sleep recordings method	Sleep indicator	Considered confounder
Diethelm, 2011 [33]	Germany	Children (both sex)	594	1.5 – 2 y	3-days weighed dietary records	Questionnaire, by asking "How many hours does your child usually sleep per 24 h?"	Sleep duration, any sleep problems, nightly eating	Gender, body weight, BMI-SDS, % body fat and overweight status, gestational age, birth year, birth weight (<3000 g), full breastfeeding (ever fully breastfed > 2 weeks), rapid weight gain between 0- and 18-month, socioeconomic status of the family (high maternal educational status (12 years of schooling), maternal overweight (BMI 25 kg/m2), smoking in the household)

Yoneyama, 2014 [34]	Japan	A factory employees (both sex)	1848	20 - 60 y	Self-administered diet history questionnaire	Japanese version of the PSQI	Subjective sleep quality, SL, sleep duration, habitual SE, sleep disturbances, use of sleep medication, and daytime dysfunction	Age, BMI, alcohol consumption, habitual exercise, smoking status, frequency of breakfast consumption, vegetable, meat, and fish intake
Kuo, 2017 [35]	Taiwan	Medical college students	108	Not mentioned	Recording dietary contents & mealtime by LINE App	PSQI	Sleep diary, sleep duration, sleep quality SL, SE	
Gangwisch, 2020 [36]	USA	Postmenopausal women	53,069	50 - 79 y	145-item FFQ designed for the WHI	WHIIRS	A 5-item instrument	Age, race/ethnicity, education, annual income, live alone, live with husband or partner, live with children, smoking status, alcohol intake, caffeine intake, stressful life events,

	social support, depression, physical activity, BMI, diabetes, hypertension, myocardial infarction, cardiovascular disease, asthma, overactive thyroid, bodily pain, hot flashes, hormone replacement therapy, snoring

BMI: Body Mass Index, SDS: Standard Deviation Scores, PSQI: Pittsburgh Sleep Quality Index, SL: Sleep Latency, SE: Sleep Efficiency, WHIIRS: Women's Health Initiative Insomnia Rating Scale

Table II.— *Summary of trials investigated the effect of meal GI on sleep quality.*

Study	Country	Participant	Sample, n	Age (range or mean)	Intervention meal	Intervention meals GI	Sleep recordings method, sleep indicators	Sleep indicators
Afaghi, 2007 [37]	Australia	Healthy normal weight men	12	18–35 y	Standard isocaloric meals including steamed rice and vegetables: 767 kcal (8% protein, 1.6% fat, 90.4% CHO) LGI meal [Mahatma rice 4 h before bedtime] HGI meal 1 [jasmine rice 4 h before bedtime] HGI meal 2 [jasmine rice 1 h before bedtime]	LGI: 50 HGI: 109	PSG, PSG indices	PSG indices
Herrera, 2010[38]	NM	Men & women	8	NM	Mixed macronutrient HGI meal vs. isoenergetic (~1915 kJ) LGI meal, 3 hours before bedtime	NM	PSG	Sleep diary, PSG indices
Jalilolghadr, 2011 [39]	Australia	Children (both sex)	8	8-12 y	• HGI drink: 200 ml low fat cow's milk with 1 tablespoon glucose (50 g of Australian Glucodin powder), GL: 52.8 • LGI drink: 200 ml of full cream cow's milk with 1 tablespoon of LGI honey (50 g of honey yellow box), GL:7.4	LGI: 23 HGI: 65	PSG	PSG indices

Misra, 2015 [40]	Malaysia	Toddlers	56	14–24 mo	Milk		Actigraphy	SOL, TST, WASO, SE
Vlahoyiannis, 2018[41]	Cyprus	Trained male	10	18 to 30 y	Standard meals including steamed rice and vegetables: 767 kcal/meal (8% protein, 1.6% fat, 90.4% CHO) LGI meal [parboiled rice, GL: 81] HGI meal [jasmine rice, GL: 170]	LGI: 52 HGI: 109	PSG	PSG indices
Daniel, 2019 [42]	Brazil	Adult male athletes	9	18.0 y	• HGI dinner: 833 kcal (17.4% protein, 19.9% fat, 62.8% CHO) • HGI evening snack: 1058 kcal (10.5% protein, 25.4% fat, 64.1% CHO) • LGI dinner: 924 kcal (20.6% protein, 23.2% fat, 56.2% CHO) • LGI evening snack: 1083 kcal (12.2% protein, 28.6% fat, 59.2% CHO)	• LGI dinner: 49.5 • LGI evening snack: 47.9 • HGI dinner: 74.9 • HGI evening snack: 71.8	actigraphy, PSQI, VAS, ESS	NTST, DTST, TST, SE, LAT, WASO

GI: glycemic index, CHO: carbohydrate, LGI: low glycemic index, HGI: high glycemic index, PSG: polysomnography, NM: not mentioned, SOL: sleep onset latency, TST: total sleep time, WASO: wake after sleep onset, SE: sleep efficiency, GL: glycemic load, PSQI: Pittsburgh Sleep Quality Index questionnaire, VAS: Visual Analogue Scale, ESS: Epworth Sleepiness Scale, NTST: nocturnal total sleep time, DTST: daytime total sleep time, LAT: sleep latency

Table III.— *Sleep-related indices evaluated in existing cross-sectional articles.*

Study	Sleep duration	Sleep quality
Diethelm et al. [33]	Sleep time was significantly higher in the group which intake HGI CHO vs. LGI (1.3 min/g, $p < 0.01$)	
Yoneyama et al. [34]		Higher dietary GI was significantly associated with lower scores for poor sleep duration ($p = 0.013$) Dietary GI was associated with good sleep (p for trend = 0.020), whereas dietary GL was not (p for trend = 0.092).
Gangwisch et al. [36]		Higher dietary GI was associated with increasing odds of prevalent (fifth compared with first quintile OR: 1.11; CI: 1.05, 1.16; P-trend = 0.0014) and incident (fifth compared with first quintile OR: 1.16; CI: 1.08, 1.25; P-trend < 0.0001) insomnia in fully adjusted models. There was a significant linear trend toward higher insomnia incidence for higher GL.
Kuo et al. [35]	The sleep duration was shortest ($p= 0.034$) in the group which intake medium GI The sleep duration was longest ($p= 0.034$) in the group which intake LGI	More sleep disturbances ($p= 0.006$) were seen in the group that take HGI

HGI: high glycemic index, CHO: carbohydrate, LGI: low glycemic index, GI: glycemic index, GL: glycemic load, OR: Odds ratio, CI: confidence interval

Table IV.— *Sleep-related indices evaluated in existing trials articles.*

Study	TST *	SE (%)	SOL (min)	NREM (%)	REM **	TWT (min)	Arousal index (no/h)
Afaghi et al. [37]	No significant diff. in TST of the group consumed HGI meal 4 h (472.0 ±66.4) vs. 1 h (478 ±68.7) before bedtime (P= 0.78).	No significant diff. in SE between the group consumed HGI meal 4 h (92.4 ±2.7) vs. 1 h (92.0 ±2.2) before bedtime (P= 0.63).	SOL was significantly lower in the group consumed HGI meal 4 h (9.0 ±6.2) vs. 1 h (14.6 ±9.9) before bedtime (P= 0.01).	NREM: No significant diff. in mean ±SD levels of the group consumed HGI meal 4 h (80.6 ±4.5) vs. 1 h (81.9 ±4.3) before bedtime (P= 0.15).	REM: No significant diff. in mean ±SD levels of the group consumed HGI meal 4 h (19.4 ±4.5) vs. 1 h (18.0 ±4.3) before bedtime (P= 0.14).	TWT: No significant diff. between the group consumed HGI meal 4 h (27.6 ±7.55) vs. 1 h (26.0 ±9.0)	REM: No significant diff. between the group consumed HGI meal 4 h (15.4 ±7.8 vs. 1 h (15.4 ±10.4) before bedtime (P= 0.99). NREM: No significant diff. between the group consumed HGI meal 4 h (10.7 ±4.5) vs. 1 h (12.1 ±5.3) before bedtime (P= 0.15). Both in REM and non-REM: No significant diff. between 4 h (11.5 ±4.2, no./h) vs. 1 h (12.6 ±5.1) before bedtime (P= 0.32).

						before bedtime (P= 0.66).	
	No significant diff. between the group consumed HGI meal 4 h (472.0 ± 66.4) vs. the group consumed LGI meal 4 h (464.1 ± 70.1) before sleep (P= 0.74)	No significant diff. in SE between the group consumed HGI meal 4 h (92.4 ±2.7) vs. the group consumed LGI meal 4 h (90.7 ± 2.7) before bedtime (P= 0.06).	SOL was significantly lower in the group consumed HGI meal 4 h (9.0 ± 6.2) vs. the group consumed LGI meal 4 h (17.5 ± 6.2) before bedtime (P= 0.009).	No significant diff. between the group consumed HGI meal 4 h (80.6 ± 4.5) vs. the group consumed LGI meal 4 h (82.6 ± 35.7) before bedtime (P= 0.77).	No significant diff. between the group consumed HGI meal 4 h (19.4 ± 4.5) and the group consumed LGI meal 4 h (90.7 ± 2.7) before bedtime (P= 0.75).	No significant diff. between consumptions of HGI meal 4 h (27.6 ± 7.55) vs. LGI meal 4 h (29.3 ± 12.7) before bedtime (P= 0.59).	REM: No significant diff. between the group consumed HGI meal 4 h (15.4 ± 7.8) vs. the group consumed LGI meal 4 h (14.5 ± 7.1) before bedtime (P= 0.70). NREM: No significant diff. between the group consumed HGI meal 4 h (10.7 ± 4.5) vs. the group consumed LGI meal 4 h (10.6 ± 5.8) before bedtime (P= 0.93). Both in REM and non-REM: No significant diff. in HGI (11.5±4.2) vs. LGI (11.4±5.3) meal groups (P= 0.95).
Jalilolgh adr et al. [39]	Total (both first and second half of night): No significant Diff. was seen between HGI (265.0 ± 25.8) vs. LGI (269.0 ± 28.4)	**First half of night**: No significant diff. in SE between HGI (90.5 ± 5.8) vs. LGI (92.3 ± 5.7) **Second half of night:** No significant diff.in SE was seen between HGI (91.7 ± 7.8) and LGI (95.1 ± 1.6)	**Total:** No significant diff. in SOL was seen between HGI (21.4 ± 17.1) and LGI (16.3 ± 16.6)	-	**First half:** No significant diff. between HGI (20.5 ±10.4) & LGI (25.9±10). **Second half:** No significant diff. between HGI (86.8±17.8) & LGI (85.4 ± 10.0)	TWT: Total: No significant diff. in TWT was seen in HGI (7.8 ± 5.1) vs. LGI (6.1 ± 2.6)	**REM:** First half: No significant diff. between HGI (11.4±11.6) vs. LGI (11.5±4.7) Second half: No significant diff. was seen between HGI (14.1±6.7) and LGI (17.5±7.4) **NREM:** First half: Mean ± SD was significantly higher in HGI (12.7 ± 4.8) vs. LGI (9.6 ± 2.3) (P= 0.049) Second half: Second half: No significant diff. was seen between HGI (12.6 ± 4.3) and LGI (11.3 ± 3.6) **Both in REM and non-REM:**

		Both halves of nights: No significant diff. was seen between HGI (265.0 ± 25.8) and LGI (269.0 ± 28.4)			**Both halves of nights:** No significant diff. between HGI (153.4± 62.5) & LGI (167.3± 53.8)		First half: Mean ± SD was significantly higher in HGI (12.9 ± 4.6) vs. LGI (9.9 ± 2.2) (P= 0.04) Second half: No significant diff. was seen between HGI (13.7 ± 4.1) and LGI (13.2 ± 4.2)		
Misra et al. [40]	No significant diff. in TST was seen in HGI (6.90 ± 1.64) vs. LGI (6.91 ± 1.51) (P= 0.560)	No significant diff. in SE was seen in HGI (86.84 ± 5.89) vs. LGI (88.29 ± 5.01) (P= 0.442)	No significant diff. in SOLwas seen in HGI (86.84 ± 5.89) vs. LGI (88.29 ± 5.01) (P= 0.442)	-	-	-	-	-	-
Vlahoyiannis et al. [41]	TST was significantly higher in HGI (426.0 ± 71.7) vs. LGI (363.6 ± 49.0) (P= 0.019)	SE was significantly higher in HGI (89.0 ± 4.3) vs. LGI (80.9 ±10.6) (P= 0.049)	SOL was significantly lower in HGI (5.7 ± 1.9) vs. LGI (24.6 ± 8.1) (P= 0.026)	-	REM: No significant Diff. in REM was seen between HGI (28.6 ± 10.9) and LGI (28.8 ± 12.2) (P= 0.959)	TWT was significantly lower in HGI (47.4 ± 21.7) vs. LGI (80.3 ± 43.6) (P= 0.034)	REM: No significant diff. was seen in between HGI (22.6 ± 8.6) and LGI (22.1 ± 12.1) (P= 0.871) NREM: No significant diff. was seen between HGI (16.4 ± 7) and LGI (18.4 ± 10.1) (P= 0.371) Both in REM and non-REM: No significant diff. was seen in between HGI (18.5±6.8) vs. LGI (19.9±10) (P= 0.24)		
Daniel et al. [42]	total sleep time (nocturnal + daytime) was (504.5 min ± 86.3) in HGI and (433.5 ± 86.9) in LGI	nocturnal SE was (89.9 ± 9.9) in HGI and (91.1 ± 6.1) in LGI Mean ± SD of daytime SE was (90.2 ± 9.8) in	SOL was 33.5 (22.0) min in HGI group compared to 46.0 (46.8) in LGI group.	-	-	-			

	HGI and (94.9 ± 8.1) in LGI

Diff. different; TST: total sleep time, SE: sleep efficiency, SOL: sleep onset latency, NREM: non-rapid eye-movement, REM: rapid eye-movement, TWT: Total wake time, WASO: Wake after sleep onset, HGI: High glycemic index, SD: standard deviation, LGI: Low glycemic index

*Except Misra et al. (hour) all were in min.

**Except Jalilolghadr et al. (min) all were in percent (%).

Table V.—*Risk of bias assessment of cross-sectional studies.*

First author, year	Representativeness of the sample	Sample size	Non-respondents	Ascertainment of the exposure	Comparability	Assessment of the outcome:	Statistical test	Quality
Diethelm, 2011 [33]	*	*	-	*	*	*	*	Good
Yoneyama, 2014 [34]	-	*	-	*	*	*	*	Fair
Gangwisch, 2020 [36]	*	*	-	*	**	*	*	Good

Kuo et al. [35] study excluded from table because of being a conference paper.

Table VI.— *Risk of bias assessment of trial studies.*

First author, year	Randomization	Randomization method	Allocation concealment	Blinding		Selective bias	Drop out	Quality
				Participants	Outcome assessor			
Afaghi,2007 [37]	Low risk	Unclear	Unclear	Unclear	Low risk	Unclear	Low risk	Poor
Jalilolghadr, 2011 [39]	Low risk	Unclear	Unclear	Unclear	Low risk	Unclear	Low risk	Poor
Misra, 2015 [40]	Low risk	Low risk	Unclear	Low risk	Low risk	High risk	Low risk	Poor
Vlahoyiannis, 2018 [41]	Low risk	Low risk	Unclear	Unclear	Low risk	Unclear	Low risk	Poor
Daniel, 2019 [42]	Low risk	Unclear	Unclear	Unclear	Unclear	Unclear	Low risk	Poor

Herrera et al [38] study excluded from table because of it was a conference paper.

Table VII.— *Strength and limitation of studies included in this systematic review*.

Study	Strength	Limitation
Afaghi et al. [37]	Monitoring of HGI and LGI diet adherence Considering the time of eating Frequent blood analysis during the study	Small sample size Lack of concurrent control group
Daniel et al. [42]	Crossover design	Small sample size No attention to noise and light exposure during sampling
Diethelm [33]and Misra [40]	Study participants were 1.5 to 2-year-old children. This is important because such cases have relatively similar diets, and sleep changes caused by stress, work, and environmental factors are very rare within this group.	Larger sample size compared to the other clinical trials in the Misra study
Kuo et al. [35]		Small sample size

Yoneyama et al. [34]	7 days diet evaluation, which is longer than the other observational studies Although the diet history questionnaire was used, researchers have tried to minimize the differences by accurately determining the type of food intake People who had sleep disorders due to their job were excluded	
Gangwisch et al. [36]	Participants were postmenopausal women, which are a specific and different study population This study has a sample size of 93767 The effect of insulin resistance index in postmenopausal women was ignored in the analysis of the results	The questionnaire used in this study for assessing sleep was WHIIRS, which is different from other studies that may be the reason for the different results of this study vs. other studies

Vlahoyiannis et al. [41]	Participants had the same diet Good sleep control conditions	Small sample size

HGI: high glycemic index, LGI: low glycemic index, WHIIRS: Women's Health Initiative Insomnia Rating Scale