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Association of sleep duration and sleep quality with the risk of metabolic syndrome in adults: a systematic review and meta-analysis

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Abstract

Introduction: The association between sleep duration and metabolic syndrome (MetS) remains controversial, and few have considered the effects of sleep quality. We performed a meta-analysis to clarify the relationship of sleep duration and sleep quality with the risk of MetS.
Material and methods: We conducted a systematic and comprehensive literature search of electronic databases from inception to 17 February 2022. The effect sizes of covariates from each study were pooled using a random or fixed model, and a restricted cubic spline random-effects meta-analysis was performed to examine the dose-response relationship between sleep duration and MetS.
Results: A total of 62 studies were included in this meta-analysis. Compared to normal sleep duration, short sleep duration [odds ratio (OR) = 1.14, 95% confidence interval (CI): 1.10–1.19] and long sleep duration (OR = 1.15, 95% CI: 1.09–1.23) were associated with an increased risk of MetS. The restricted cubic spline analysis indicated that sleep durations of 8.5 h (OR = 0.95, 95% CI: 0.92–0.97) and 11 h (OR = 1.58, 95% CI: 1.31–1.91) were significantly associated with the risk of MetS. The pooled results showed that poor sleep quality (OR = 1.46, 95% CI: 1.03–2.06) and sleep complaints had significant positive associations with MetS.
Conclusion: Our results demonstrated that short sleep duration increased the risk of developing MetS. Long sleep duration was also associated with MetS, especially for 11 h. 8.5 h can be considered the recommended sleep duration for MetS. Poor sleep quality and sleep complaints were also associated with MetS.

Key words: *sleep duration; sleep quality; metabolic syndrome; meta-analysis*

Introduction

Metabolic syndrome (MetS), characterised by a cluster of interdependent risk factors including abdominal obesity, hypertension, hyperglycaemia, and dyslipidaemia [1], is significantly correlated with an increased risk of cardiovascular disease, cancer, and mortality [2–6]. The prevalence of MetS is rapidly growing worldwide; 34.7% of the adult population in the US and 33.9% in China suffer from MetS [7, 8]. Thus, the early identification and control of modifiable risk factors associated with the development of MetS are vital to public health.

Sleep is a state of energy restoration and replenishment that accounts for approximately one-third of a human's lifetime [9]. With growing mental stress in society, sleep problems are becoming increasingly severe and have attracted widespread attention. Sleep duration and quality are the most important aspects of sleep profiles [10, 11]. Several studies have shown that sleep duration and sleep quality not only have additive effects on health outcomes, but can also independently have different effects on health [12, 13], indicating that the potential differences in health effects between the 2 independent domains of sleep assessment should be considered. Current research shows that poor sleep is related to adverse outcomes such as obesity, diabetes, cardiovascular disease, and all-cause mortality [9, 10, 14–17], which suggests that it might be associated with an increased risk of MetS.

Several epidemiological studies have investigated the association between sleep duration and MetS, with inconsistent results. The findings of a meta-analysis published recently summarised 38 articles reporting that short and long sleep duration were associated with a high prevalence of MetS, presenting a "U-shaped" relationship by merging the effect sizes of different sleep groups [18], while others only found an association between short sleep duration and MetS [19–21].

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The relationship between long sleep duration and MetS remains controversial [18–23]. Although previous reviews have evaluated the association between sleep duration and MetS, the dose-response association remains unclear. Additionally, many studies have focused only on sleep duration, and few have considered the influence of sleep quality [24]. Since more eligible original studies have been conducted, a reanalysis of the relationship between sleep duration and MetS is required, and specific dose-response relationships should also be verified. Therefore, we performed a systematic meta-analysis combining 53 articles to update the relationship between sleep duration and MetS, and then evaluated the association between sleep quality and MetS for the included studies involving overall sleep quality or sleep disorders, which has rarely been mentioned in previous studies.

Material and methods

The present study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines [25]. This meta-analysis was registered in the PROSPERO database (registration number: CRD42021251459).

Search strategy

We systematically searched electronic databases, including PubMed, Embase, Ovid, and Web of Science, from inception to 17 February 2022. The search strategy to identify all possible studies involved the use of the following terms: "sleep" and "syndrome X" or "metabolic syndromes" or "metabolic syndromes X" or "insulin resistance syndrome" or "MS" or "MetS"; and the literature search was limited to English language. In addition, we screened the reference lists of all obtained articles and relevant reviews, and manually searched for other studies that met the inclusion criteria to avoid missing relevant articles.

Study selection

Studies were included in this meta-analysis if they satisfied the following criteria: (1) the population comprised only adults (age ≥ 18 years); (2) used a cross-sectional or cohort design; (3) defined MetS as the outcome variable and sleep duration as the exposure variable; and (4) reported usable risk estimates and 95% confidence interval (CI) or sufficient data for calculation. The exclusion criteria were as follows: (1) review or meta-analysis; (2) editorials; (3) only defined components of MetS as outcome variables; (4) no information on sleep duration can be extracted; (5) combined with other diseases; and (6) the criteria for MetS were unclear or absent. In addition, if multiple articles were conducted in the same population, only the article with the largest sample was included in further analysis.

Data extraction and quality assessment

Two independent researchers (JY Hu and XY Zhu) separately assessed the articles for compliance with the inclusion/exclusion criteria and resolved disagreements by reaching a consensus, with adjudication by a third researcher (B Wang) if a discrepancy persisted. The following contents were collected: (1) name of the first author; (2) publication year; (3) study design; (4) country of origin; (5) participant characteristics (age and sex); (6) number of subjects in MetS cases and healthy controls; (7) measurements (sleep measurements and MetS criteria); (8) categories of sleep duration; (9) risk estimates and 95% CI; and (10) the covariates used in adjustment.

The quality of the included studies was evaluated according to the Newcastle-Ottawa Quality Assessment Scale (NOS), which carefully scrutinised 3 aspects: selection, comparability, and exposure [26]. Total scores of 0–3, 4–6, and 7-9 were considered low, moderate, and high quality, respectively.

Definitions

Because the sleep duration categories varied among different cultures and ethnicities [27], the definitions of short, normal, and long sleep durations were derived from the original articles. If sleep duration was divided into more than 3 groups, short or long sleep duration was defined as the shortest or longest range, as reported previously. In addition, we classified the source of sleep duration into 2 categories: night-time sleep duration and 24-h sleep duration (including night-time sleep and daytime naps). If the study reported both night-time and 24-h sleep duration, only the night-time sleep duration was used. Sleep duration was assessed using 3 methods: self-administered questionnaires (interview or self-reported), standard questionnaires [Pittsburgh Sleep Quality Index (PSQI)], and objective sleep measurements (polysomnography, accelerometry, or wrist actigraph).

Outcome measures

The primary outcome of this meta-analysis was the association between sleep duration and the risk of MetS. For the original articles that reported at least 4 levels of sleep categories, we performed a restricted cubic spline random-effects meta-analysis to assess the dose-response relationship between sleep duration and MetS. Daily sleep duration of 7–8 h was used as the reference group based on most of the original articles [28]. The secondary outcome was the association between sleep quality and risk of developing MetS. Among the included studies, articles referring to overall sleep quality or sleep complaints, including use of sleep medication, difficulty falling asleep, difficulty maintaining sleep, early morning awakening, insomnia symptoms, and sleep-related breathing disorders, were used to examine the relationship between sleep quality and MetS.

Statistical analysis

The heterogeneity between studies was tested using Q statistics ($p < 0.1$ indicates statistical significance) and I^2 index ($I^2 > 50\%$ indicates statistical significance). A random [29] or fixed [30] effects model was used to pool the effect sizes of covariates from each study according to heterogeneity. In this meta-analysis, we used the odds ratios (ORs), hazard ratios (HRs), and risk ratios (RRs) with corresponding 95% CIs, adjusted for most covariates according to the original articles. The HRs reported in cohort studies were regarded as RRs. Furthermore, several sensitivity analyses were conducted to evaluate the stability of the results, and publication bias was assessed using funnel plots and Begg's test [31].

We conducted subgroup analyses based on the study design, ethnicity, sex, study population, source of sleep duration, measurements of sleep duration, MetS criteria, and reference of sleep duration on the association between sleep duration and the risk of MetS. A restricted cubic spline random-effects meta-analysis with 4 knots at fixed percentiles (5, 35, 65, and 95%) of the distribution was performed to examine the dose-response relationship between sleep duration and MetS. STATA 15.0 (version 15.1, StataCorp, College Station, TX) was used for all analyses, and a two-sided $p \leq 0.05$ was considered as statistically significant.

Results

Characteristics of studies

The study selection process is illustrated in Figure 1. A total of 7132 potentially relevant articles were iden-
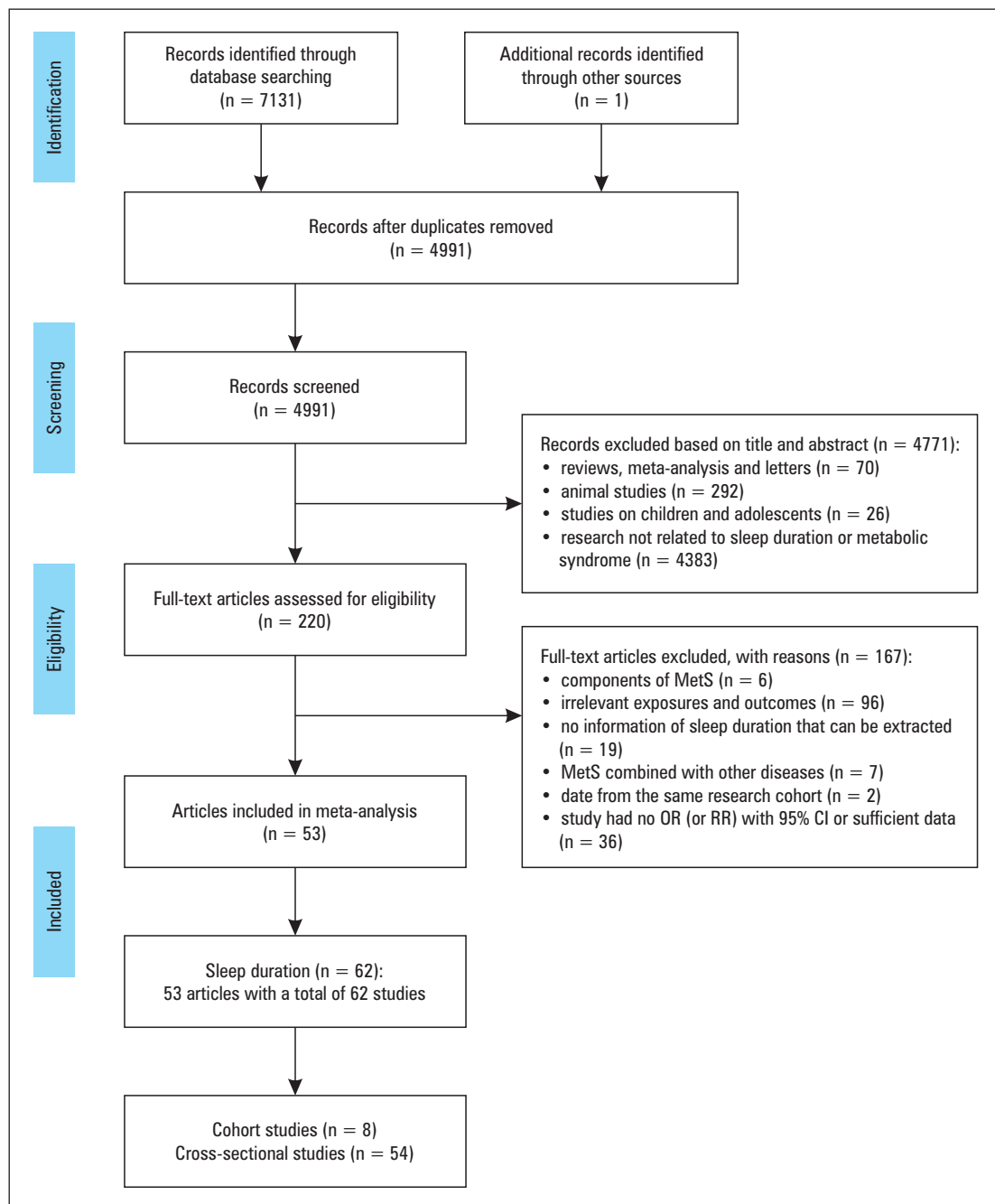
Figure 1. *Flow chart of meta-analysis for exclusion/inclusion studies. OR — odds ratio; RR — relative risk; CI — confidence interval*

tified through literature and manual search. A total of 2141 duplicate articles were excluded by preliminary screening, and 4771 articles were excluded due to apparent irrelevance after reading the titles and abstracts. After reviewing 220 full texts, 53 articles were involved, including 46 cross-sectional studies and 7 cohort studies. Since the data of 8 studies were provided by sex and one by menopausal status, they were considered as separate studies in the subsequent data analysis. Therefore, 62 studies (874,367 participants) were included in the final meta-analysis, of which 54 were cross-sectional studies and 8 were cohort studies [32–84]. In cross-sectional studies, 40 studies assessed short sleep duration using self-administered questionnaires, 5 used PSQI, and 3 used objective sleep measurements. For the measurements of long sleep duration, 38 studies used self-administered questionnaires, 3 used PSQI, and 3 used objective sleep measurements. Self-administered questionnaires were used measure short and long sleep durations in the cohort study. Among the 62 included studies, 13 (15 separate studies involving 93,773 participants) reported an association between sleep quality

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and the risk of MetS (48, 49, 52, 55, 56, 63, 68, 70-72, 74, 75, 80), which included 14 cross-sectional studies and one cohort study. The primary characteristics of the included studies are presented in Table 1.

Sleep duration and MetS

Compared with normal sleep duration, short sleep duration (OR = 1.14, 95% CI: 1.10–1.19, p < 0.001) and long sleep duration (OR = 1.15, 95% CI: 1.09–1.23, p < 0.001) were significantly associated with an increased risk of MetS. Short sleep duration was related to the risk of MetS both in cross-sectional studies (OR = 1.13, 95% CI: 1.08–1.18, p < 0.001) and cohort studies (RR = 1.21, 95% CI: 1.10–1.34, p < 0.001). However, a significant relationship was observed only between long sleep duration and the risk of MetS in cross-sectional studies (OR = 1.15, 95% CI: 1.08–1.22, p < 0.001), and no association was found in cohort studies (RR = 1.21, 95% CI: 0.93–1.58, p = 0.150) (Fig. 2).

Subgroup analysis of sleep duration and MetS

The results of subgroup analyses are presented in Table 2. In cross-sectional studies, there were significant associations between short or long sleep duration and the risk of MetS in Caucasians and Asians; however, no association was detected in Africans (Tab. 2). After stratification by sex, short sleep duration increased the risk of MetS both in men (RR = 1.08, 95% CI: 1.03–1.13, p = 0.004) and women (RR = 1.80, 95% CI: 1.06–3.05, p = 0.030) among cohort studies, and a significant association was observed only in men (OR = 1.26, 95% CI: 1.11–1.42, p < 0.001) among cross-sectional studies. Moreover, the correlation between long sleep duration and the risk of MetS in both men and women was only found in cross-sectional studies (Tab. 2). The summary ORs/RRs and their 95% CI indicated that short sleep duration was associated with the risk of MetS among the community, hospital, and company or office populations for both cross-sectional and cohort studies. Similar findings were also found in cross-sectional studies on the relationship between long sleep duration and an increased risk of MetS (Tab. 2). Additionally, we observed that short sleep duration defined by night-time or 24-h sleep duration was related to the risk of MetS in both cross-sectional and cohort studies. Long sleep duration defined by 24-h sleep duration (OR = 1.16, 95% CI: 1.08–1.25, p < 0.001) was associated with increased prevalence of MetS in cross-sectional studies, while the association between long sleep duration defined by night-time sleep duration (RR = 1.42, 95% CI: 1.18–1.71, p < 0.001) and increased prevalence of MetS was found in cohort studies (Tab. 2). Furthermore, subgroup analysis stratified by measurements of sleep duration revealed a significant relationship between either short (OR = 1.14,

Table 1. *Characteristics of included studies*

Study	Country	Study design	Participants (N)	Cases (N)	Male (%)	Mean age (range)	Study population	MetS criteria[a]	Measurement (sleep duration/sleep quality)	Source of sleep duration	Sleep category [h]	Adjustment covariates[b]
Santos[a], 2007 [39]	Portugal	Cross-sectional	832	140	100.00	18–92	Community	NCEP ATP III	Self-administered questionnaires	24 h	Short ≤ 6 / Ref ≥ 9	1, 5, 6, 7
Santos[b], 2007 [39]	Portugal	Cross-sectional	1332	296	0.00	18–92	Community	NCEP ATP III	Self-administered questionnaires	24 h	Short ≤ 6 / Ref ≥ 9	1, 5, 6, 7
Choi, 2008 [40]	Korea	Cross-sectional	4222	1100	43.15	44.10 (≥ 20)	Community	NCEP ATP III (modified)	Self-administered questionnaires	Night	Short ≤ 5 / Ref 7 / Long ≥ 9	1, 2, 3, 5, 6, 7, 8, 13, 14, 15
Hall, 2008 [41]	USA	Cross-sectional	1214	272	46.79	44.40 (30–54)	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short < 6 / Ref 7–8 / Long > 8	1, 2, 4, 5, 6, 8, 12, 25

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Kobayashi, 2011 [42]	Japan	Cross-sectional	44,452	3876	49.46	44.80 (≥ 20)	Hospital	Japanese criteria	Self-administered questionnaires	Night	Short < 6 Ref ≥ 8	1, 2, 6, 7, 8, 30
Najafian, 2011 [43]	Iran	Cross-sectional	12,492	2936	48.91	38.89 (> 19)	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short ≤ 5 Ref 7–8 Long ≥ 9	1, 2
Arora, 2011 [44]	China	Cross-sectional	29,333	8222	27.59	61.51 (50–96)	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Short < 6 Ref 7–8 Long ≥ 9	1, 2, 5, 6, 7, 8, 11, 19, 23, 26, 30, 31, 32, 37
McCanlies, 2012 [45]	USA	Cross-sectional	98	14	60.20	39.61	Company or office	AHA/NHLBI	Self-administered questionnaires	Night	Short < 6 Ref ≥ 6	1, 2, 5, 6,
Sabanayagam, 2012 [46]	USA	Cross-sectional	6122	2284	51.81	44.63 (≥ 20)	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short ≤ 5 Ref 7 Long ≥ 9	1, 2, 4, 5, 6, 7, 8, 12
Wu[a], 2012 [47]	China	Cross-sectional	4298	760	100.00	20–90	Hospital	NCEP ATP III (modified)	Self-administered questionnaires	Night	Short < 6 Ref 6–8 Long > 8	1, 3, 5, 6, 7, 8
Wu[b], 2012 [47]	China	Cross-sectional	2802	275	0.00	20–90	Hospital	NCEP ATP III (modified)	Self-administered questionnaires	Night	Short < 6 Ref 6–8 Long > 8	1, 3, 5, 6, 7, 8
Lee, 2013 [48]	Korea	Cross-sectional	301	106	62.13	50.80 (≥ 20)	Hospital	NCEP ATP III (modified)	PSQI/PSQI	24h	Short ≤ 5 Ref 7 Long ≥ 9	1, 2, 5, 6, 7, 8, 12, 15, 16, 17
Yoo, 2013 [49]	USA	Cross-sectional	106	35	82.08	42.30 (22–60)	Company or office	AHA/NHLBI (modified)	PSQI/PSQI	Night	Short ≤ 6 Ref 6–8 Long ≥ 8	1, 2, 6, 8, 12, 17, 38
Chaput, 2013 [50]	Canada	Cross-sectional	810	199	42.96	40.05 (18–65)	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short ≤ 6 Ref 7–8 Long ≥ 9	1, 2, 5, 6, 7, 8, 9, 15, 29

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Stefani, 2013 [51]	Korea	Cross-sectional	24,511	6103	40.79	20–79	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Short ≤ 5 Ref 7 Long ≥ 9	1, 2, 3, 5, 6, 7, 8, 16
Ikeda, 2014 [52]	Japan	Cross-sectional	3936	757	40.45	56.50 (≥ 20)	Community	Japanese criteria	Self-administered questionnaires/ self-administered questionnaires	24 h	Short ≤ 5 Ref 6–7 Long ≥ 8	1, 2, 6, 7, 8, 17, 27
Yu, 2014 [53]	China	Cross-sectional	11,496	4488	46.18	53.82 (≥ 35)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Ref ≤ 7 Long ≥ 9	1, 4, 5, 6, 7, 8, 10, 13, 15, 27, 28, 44
Saleh, 2014 [54]	USA	Cross-sectional	1371	512	56.16	49.00 (≥ 20)	Community	AHA/NHLBI	Objective (accelerometry)	Night	Short 3.0–7.2 Ref 7.2–8.6 Long 9.7–11.8	1, 2, 4, 5, 6, 7, 8, 18, 29, 39, 40
Okubo[a], 2014 [55]	Japan	Cross-sectional	549	105	100.00	57.10 (20–80)	Community	Japanese criteria	PSQI/PSQI	Night	Short < 5 Ref > 7	1, 6, 7, 8, 12, 41
Okubo[b], 2014 [55]	Japan	Cross-sectional	932	63	0.00	57.90 (20–80)	Community	Japanese criteria	PSQI/PSQI	Night	Short < 5 Ref > 7	1, 6, 7, 8, 12, 41
Chang, 2015 [56]	China	Cross-sectional	796	195	100.00	37.36 (20–60)	Company or office	AHA/NHLBI (modified)	Self-administered questionnaires/ PSQI	24 h	Short < 5 Ref 7–8 Long ≥ 8	1, 6, 7, 8, 25, 32, 35
Canuto, 2015 [57]	Brazil	Cross-sectional	902	84	34.04	31.00 (18–50)	Company or office	AHA/NHLBI	Self-administered questionnaires	Night	Short < 5 Ref ≥ 5	1, 4, 5, 6, 7, 8, 10, 15, 27, 35
Wu[a], 2015 [58]	China	Cross-sectional	11,370	2720	100.00	63.60	Company or office	IDF	Self-administered questionnaires	24 h	Short < 7 Ref 7–8 Long ≥ 10	1, 3, 5, 6, 7, 8, 10, 13
Wu[b], 2015 [58]	China	Cross-sectional	13,814	5,326	0.00	63.60	Company or office	IDF	Self-administered questionnaires	24 h	Short < 7 Ref 7–8 Long ≥ 10	1, 3, 5, 6, 7, 8, 10, 13

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Haba-Rubio, 2015 [59]	Switzerland	Cross-sectional	2162	659	48.84	58.40 (35–75)	Community	NCEP ATP III	Objective (polysomnography)	Night	Short < 6 / Ref 7–8 / Long ≥ 8	1, 2, 6, 7, 8, 12, 30
Lim, 2015 [60]	Korea	Cross-sectional	1728	N/A	34.14	51.20 (> 20)	Hospital	NCEP ATP III	Self-administered questionnaires	N/A	Ref < 5 / Long >8	1, 2, 5, 6, 7, 17, 18
Xiao, 2016 [61]	China	Cross-sectional	20,502	4422	34.13	54.20 (18–74)	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Ref ≤7 / Long > 8	1, 2, 3, 5, 6, 7, 8, 10, 15, 16, 27, 28, 39, 40
Min, 2016 [62]	Korea	Cross-sectional	8505	1338	0.00	43.30 (20–75)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short ≤ 5 / Ref 7 / Long ≥ 9	1, 3, 5, 6, 7, 8, 15, 27
Lin, 2016 [63]	China	Cross-sectional	4197	880	46.41	47.94	Community	AHA/NHLBI	Self-administered questionnaires/ ISAI	Night	Short < 7 / Ref 7–8 / Long ≥ 9	1, 2, 6, 27
Rao, 2016 [64]	Canada	Cross-sectional	2901	551	N/A	≥ 18	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Short < 7 / Ref 7–8 / Long ≥ 8	1, 2, 5, 6, 7, 15
Yoon, 2016 [65]	Korea	Cross-sectional	72,673	19,125	33.48	40–69	Hospital	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–7 / Long ≥ 10	
Cole, 2017 [66]	Ghana	Cross-sectional	263	52	41.06	47.60 (≥ 25)	Community	AHA/NHLBI	Objective (wrist actigraphs)	Night	Short < 7 / Ref 7–8 / Long >8	1, 2, 8, 12, 14, 18, 33
Suliga, 2017 [67]	Poland	Cross-sectional	10,367	5333	29.48	37–66	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short ≤ 6 / Ref 7–8 / Long ≥ 9	1, 2, 5, 6, 7, 8, 10, 14, 29, 36, 40
Zohal, 2017 [68]	Iran	Cross-sectional	1079	330	46.43	40.08 (20–72)	Community	AHA/NHLBI	Self-administered questionnaires/PSQI	Night	Short < 6 / Ref 6–8 / Long >8	1, 2, 3

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Kim a, 2018 [69]	Korea	Cross-sectional	44,930	13,072	100.00	53.60 (40–69)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long ≥ 10	1, 5, 6, 7, 8, 9, 16, 27
Kim b, 2018 [69]	Korea	Cross-sectional	88,678	21,754	0.00	52.30 (40–69)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long ≥ 10	1, 5, 6, 7, 8, 9, 16, 27
van der Pal, 2018 [70]	Netherlands	Cross-sectional	1679	447	47.41	60.80 (40–75)	Community	NCEP ATP III	Self-administered questionnaires/ESS	Night	Short < 7 / Ref 7–8 / Long ≥ 9	1, 2, 3, 5, 6, 8, 12, 16
Titova, 2018 [71]	Sweden	Cross-sectional	19,691	4941	43.43	60.80	Community	AHA/NHLBI	Self-administered questionnaires/ self-administered questionnaires	24 h	Short ≤ 6 / Ref 7–8 / Long ≥ 9	1, 2, 5, 6, 7, 8
Ostadrahimi, 2018 [72]	Iran	Cross-sectional	14,916	5104	44.75	35–70	Community	AHA/NHLBI	PSQI/PSQI	24 h	Short < 6 / Ref 6–9 / Long >9	1, 2, 3, 10, 14, 39, 42
Kim[a], 2019 [73]	Korea	Cross-sectional	2049	579	100.00	19–64	Company or office	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Ref < 6 / Long ≥ 8	1, 2, 3, 5, 6, 7, 8, 16, 17, 18, 27, 41
Kim[b], 2019 [73]	Korea	Cross-sectional	2617	442	0.00	19–64	Company or office	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Ref < 6 / Long ≥ 8	1, 2, 3, 5, 6, 7, 8, 16, 17, 18, 27, 41
Qian, 2019 [74]	China	Cross-sectional	4579	919	48.05	67.64 (≥ 60)	Community	NCEP ATP III (modified)	Self-administered questionnaires/ Self-administered questionnaires	Night	Short < 7 / Ref 7–8 / Long ≥ 11	1, 2, 5, 6, 7, 15, 27, 28, 42
Gaston[a], 2019 [75]	USA	Cross-sectional	13,988	787	0.00	46.80 (35–74)	Community	AHA/NHLBI	Self-administered questionnaires/ Self-administered questionnaires	N/A	Short < 7 / Ref 7–9	1, 5, 6, 7, 8, 12, 15, 27, 30

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Gaston[b], 2019 [75]	USA	Cross-sectional	24,019	3725	0.00	59.80 (35–74)	Community	AHA/NHLBI	Self-administered questionnaires/Self-administered questionnaires	N/A	Short < 7, Ref 7–9	1, 5, 6, 7, 8, 12, 15, 27, 30
Fan, 2020 [76]	China	Cross-sectional	8272	2503	40.57	51.50 (≥ 18)	Community	Chinese criteria	Self-administered questionnaires	24 h	Short < 6, Ref 6–9, Long > 9	
Xu, 2020 [77]	China	Cross-sectional	20,862	2926	47.28	43.40 (18–80)	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Short < 6, Ref ≥ 6	1, 2, 3, 4, 6, 7, 13, 16, 27
Lu, 2020 [78]	China	Cross-sectional	4144	1509	100.00	47.04 (> 18)	Company or office	Chinese criteria	Self-administered questionnaires	N/A	Short < 6, Ref 7, Long > 8	1, 35, 6, 7, 8, 12
Ghazizadeh, 2020 [79]	Iran	Cross-sectional	9652	3859	39.96	48.01	Community	IDF	Self-administered questionnaires	24 h	Short < 6, Ref 6–8, Long > 8	1, 3, 5, 6, 8, 15, 16, 42, 43
Wang, 2021 [80]	China	Cross-sectional	7052	1533	46.87	45.70 (18–64)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 7, Ref 7–9, Long > 9	1, 2, 5, 6, 7, 8, 14, 27
Aryannejad, 2021 [81]	Iran	Cross-sectional	30504	9742	35.75	41.70 (20–65)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Ref ≤ 5, Long ≥ 10	1, 2, 4, 5, 6, 8, 13, 14, 45
Li, 2021 [82]	China	Cross-sectional	4785	209	50.20	≥ 65	Community	Chinese criteria	Self-administered questionnaires	Night	Short < 7, Ref 7–8, Long > 8	1, 2, 5, 6, 7, 8, 10, 11, 14, 45, 46, 47, 48, 49
Feng, 2021 [83]	USA	Cross-sectional	11,181	2917	48.39	≥ 16	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short < 7, Ref 7–8, Long ≥ 8	1, 2, 4, 5, 6, 7, 10, 40, 45

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Table 1. *Characteristics of included studies*

Study	Country	Study design	Participants (N)	Cases (N)	Male (%)	Mean age (range)	Study population	MetS criteria[a]	Measurement (sleep duration/sleep quality)	Source of sleep duration	Sleep category [h]	Adjustment covariates[b]
Katsuura-Kamano[a], 2021 [84]	Japan	Cross-sectional	14,907	3371	100.00	54.60 (35–69)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long ≥ 8	1, 5, 6, 7, 8, 27, 50, 51
Katsuura-Kamano[b], 2021 [84]	Japan	Cross-sectional	14,873	1562	0.00	53.80 (35–69)	Community	NCEP ATP III (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long ≥ 8	1, 5, 6, 7, 8, 9, 27, 50, 51
Choi[a], 2011 [32]	Korea	Cohort	386	82	100.00	48.97 (40–70)	Community	AHA/NHLBI (modified)	Self-administered questionnaires	Night	Short < 6 / Ref 6–8 / Long ≥ 10	1, 3, 6, 7, 8
Choi[b], 2011 [32]	Korea	Cohort	721	122	0.00	48.23 (40–70)	Community	AHA/NHLBI (modified)	Self-administered questionnaires	Night	Short < 6 / Ref 6–8 / Long ≥ 10	1, 3, 6, 7, 8, 9
Kim, 2015 [33]	Korea	Cohort	2579	558	35.40	55.75 (40–70)	Community	AHA/NHLBI (modified)	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long ≥ 10	1, 2, 5, 6, 7, 8, 27
Li, 2015 [34]	China	Cohort	4774	1506	52.28	50.22 (30–65)	Community	AHA/NHLBI	Self-administered questionnaires	Night	Short < 6 / Ref 7–8 / Long ≥ 9	1, 2, 5, 6, 7, 8, 11, 13, 17, 19, 21, 22, 26, 30, 31, 32, 33
Song, 2016 [35]	China	Cohort	15,753	6302	82.77	47.33 (19–98)	Hospital	AHA/NHLBI (modified)	Self-administered questionnaires	Night	Short ≤ 5.5 / Ref 7 / Long ≥ 8.5	1, 2, 3, 5, 6, 7, 8, 10, 15, 32, 34
Itani, 2017 [36]	Japan	Cohort	39,182	6622	100.00	42.40 (18–65)	Company or office	Japanese criteria	Self-administered questionnaires	24 h	Short < 5 / Ref ≥ 5	1, 6, 7, 11, 27, 35, 36
Deng, 2017 [37]	China	Cohort	162,121	24,637	47.41	20–80	Community	AHA/NHLBI	Self-administered questionnaires	24 h	Short < 6 / Ref 6–8 / Long >8	1, 2, 3, 5, 6, 7, 8, 10, 19, 20, 21, 22, 23, 24, 26

Table 1. *Characteristics of included studies*

Study	Country	Study design	Participants (N)	Cases (N)	Male (%)	Mean age (range)	Study population	MetS criteria[a]	Measurement (sleep duration/sleep quality)	Source of sleep duration	Sleep category [h]	Adjustment covariates[b]
Wang, 2021 [38]	China	Cohort	3005	406	51.48	71.31 (≥ 60)	Community	NCEP ATP III (modified)	Self-administered questionnaires/ self-administered questionnaires	Night	Short ≤ 6 Ref 7–8 Long ≥ 9	1, 2, 5, 6, 7

[a]NCEP ATPIII — National Cholesterol Education Program Adult Treatment Panel III criteria; NCEP ATPIII (modified) — National Cholesterol Education Program Adult Treatment Panel III criteria (abdominal obesity assessed by Asian criteria, WHO criteria, body mass index (BMI) ≥ 25 kg/m², BMI ≥ 30 kg/m² or others; fasting plasma glucose (FPG) ≥ 7.0 mmol/L or with a history of diabetes mellitus; diabetes mellitus defined as a casual plasma glucose ≥ 200 mg/dL (11.1 mmol/L) or a self-reported history of physician-diagnosed diabetes); AHA/NHLBI — Scientific Statement of American Heart Association/National Heart, Lung, and Blood Institute; AHA/NHLBI (modified) — Scientific Statement of American Heart Association/National Heart, Lung, and Blood Institute (abdominal obesity assessed by Asian criteria, Korean criteria); IDF — International Diabetes Federation. Japanese criteria: CEDSMS — the diagnostic criteria set by the Japanese Committee to Evaluate Diagnostic Standards for Metabolic Syndrome; JASSO — Japan Society for the Study of Obesity). Chinese criteria: Dyslipidaemia Prevention and Cure Guidelines of China in 2007 and Chinese Diabetes society (CDS); [b]1 — age; 2 — sex; 3 — BMI; 4 — race; 5 — education; 6 — smoking; 7 — alcohol intake; 8 — physical activity; 9 — menopause (female); 10 — marital status; 11 — mental disease; 12 — depression; 13 — family history of hypertension or diabetes, stroke, cardiovascular disease and others; 14 — residential area; 15 — income; 16 — occupation; 17 — stress; 18 — economic status; 19 — systolic blood pressure; 20 — diastolic blood pressure; 21 — waist circumference (WC); 22 — fasting blood glucose (FBG); 23 — total cholesterol (TG); 24 — high-density lipoprotein cholesterol (HDL-C); 25 — low-density lipoprotein cholesterol (LDL-C); 26 — triglycerides (TG); 27 — daily caloric intake/ dietary intake/eating habits; 28 — tea consumption; 29 — coffee; 30 — past medical history; 31 — insomnia; 32 — snoring; 33 — sleep quality; 34 — resting heart rate; 35 — shift work; 36 — walking; 37 — daytime sleepiness; 38 — burnout; 39 — screen time; 40 — sedentary time; 41 — work time/work type; 42 — nap; 43 — household size; 44 — numbers of child; 45 — insurance; 46 — vision impairment; 47 — disability status; 48 — sleep disturbance; 49 — self-rated health; 50 — research site; 51 — nutrient pattern; MetS — metabolic syndrome; PSQI — Pittsburgh Sleep Quality Index; ISAI — Insomnia Self-Assessment Inventory questionnaire; ESS — self-reported questions and the Epworth Sleepiness Scale; N — number; h — hour; Ref — reference

95% CI: 1.08–1.19, p < 0.001) or long sleep duration (OR = 1.15, 95% CI: 1.08–1.23, p < 0.001) recorded by self-administered questionnaires and MetS in cross-sectional studies, while the association was not found in PSQI and objective sleep measurements (Tab. 2).

Dose-response relationship between sleep duration and MetS

The results of the restricted cubic spline random-effects meta-analysis, which included 22 studies (16 cross-sectional studies and 6 cohort studies), demonstrated a nonlinear relationship between sleep duration and MetS (p < 0.001). Compared with normal sleep duration (7–8 h per day), 8.5 h (OR = 0.95, 95% CI: 0.92–0.97) and 11 h (OR = 1.58, 95% CI: 1.31–1.91) were significantly associated with the risk of MetS. Similar findings were also observed in cross-sectional studies (p < 0.001) (Fig. 3). However, for cohort studies, the restricted cubic spline analysis presented a nonlinear relationship (p < 0.001), in which 5.25 h and 11 h were positively related to MetS and 8.5 h was negatively related to MetS, compared with the normal sleep duration. The combined ORs of MetS were 1.08 (95% CI: 1.01–1.16) for 5.25 h, 0.84 (95% CI: 0.77–0.93) for 8.5 h and 2.58 (95% CI: 1.25–5.33) for 11 h, respectively (Fig. 3).

Sleep quality and MetS

Among the 15 studies included to assess the association between sleep quality and the risk of MetS, 8 studies reported overall sleep quality, and 7 reported sleep complaints. To measure overall sleep quality, PSQI was used in 6 studies, and 2 used self-administered questionnaires. The total PSQI scores ranged from 0 to 21 points, with higher scores indicating poorer sleep quality. PSQI scores greater than 5 points were defined as poor sleep quality [85].

As shown in Table 3, the pooled results indicated that poor sleep quality increased the risk of MetS (OR = 1.46, 95% CI: 1.03–2.06, p = 0.033), and this relationship was observed in cross-sectional studies (OR = 1.54, 95% CI: 1.02–2.32, p = 0.041) and was not found in cohort studies (RR = 1.20, 95% CI: 0.82–1.76, p = 0.349). Furthermore, sleep complaints, including use of medication, difficulty falling asleep, difficulty maintaining sleep, and sleep-related breathing disorder, had significant positive associations with MetS (Tab. 3). Excluding one cohort study, the findings of subgroup analysis stratified by sex revealed that overall sleep quality was related to the risk of MetS in women among cross-sectional studies (OR = 2.71, 95% CI: 1.45–5.07, p = 0.002); in contrast, no association was found in men (OR = 1.31, 95% CI: 0.44–3.89, p = 0.625). Additionally, we only observed a significant relationship between overall
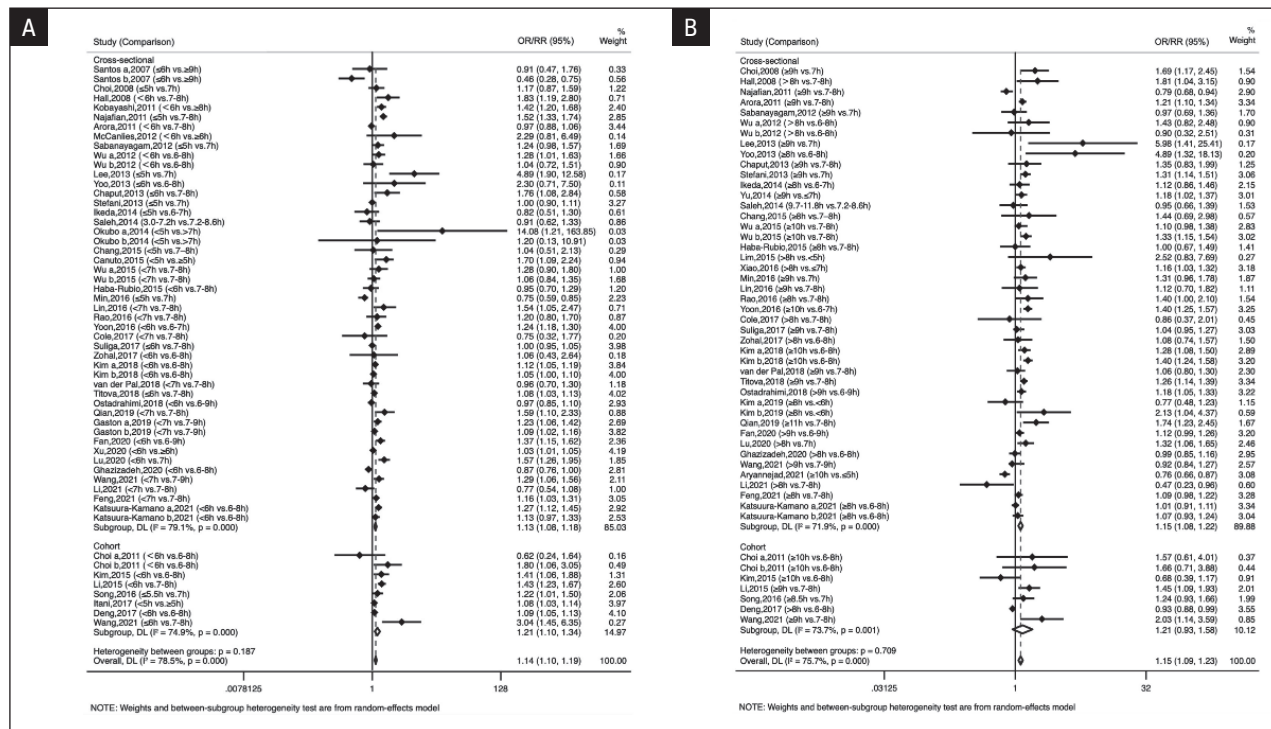
REVIEW

A

Study (Comparison)	OR/RR (95%)	% Weight
Cross-sectional		
Santos a,2007 (≤5h vs.≥9h)	0.91 (0.47, 1.76)	0.33
Santos b,2007 (≤6h vs.≥9h)	0.46 (0.28, 0.75)	0.56
Choi,2008 (≤5h vs.7h)	1.17 (0.87, 1.59)	1.22
Hall,2008 (<6h vs.7-8h)	1.83 (1.19, 2.80)	0.71
Kobayashi,2011 (<6h vs.≥6h)	1.42 (1.20, 1.68)	2.40
Najafian,2011 (≤5h vs.7-8h)	1.52 (1.33, 1.74)	2.85
Arora,2011 (<6h vs.7-8h)	0.97 (0.88, 1.06)	3.44
McCanlies,2012 (<6h vs.≥6h)	2.29 (0.81, 6.49)	0.14
Sabanayagam,2012 (≤5h vs.7h)	1.24 (0.98, 1.57)	1.69
Wu a,2012 (<6h vs.6-8h)	1.28 (1.01, 1.63)	1.66
Wu b,2012 (<6h vs.6-8h)	0.90 (0.72, 1.51)	0.90
Lee,2013 (<6h vs.7h)	4.89 (1.90, 12.58)	0.17
Yoo,2013 (≤5h vs.6-8h)	2.30 (0.71, 7.50)	0.11
Chaput,2013 (≤6h vs.7-8h)	1.76 (1.08, 2.84)	0.58
Stefani,2013 (≤5h vs.7h)	1.00 (0.90, 1.11)	3.27
Ikeda,2014 (≤5h vs.6-7h)	0.82 (0.51, 1.30)	0.61
Saleh,2014 (3.0-7.2h vs.7.2-8.6h)	0.91 (0.62, 1.33)	0.86
Okubo a,2014 (<5h vs.>7h)	14.08 (1.21, 163.85)	0.03
Okubo b,2014 (<5h vs.>7h)	1.20 (0.13, 10.91)	0.03
Chang,2015 (<5h vs.7-8h)	1.04 (0.51, 2.13)	0.29
Canuto,2015 (<5h vs.≥5h)	1.70 (1.09, 2.24)	0.94
Wu a,2015 (<7h vs.7-8h)	1.28 (0.90, 1.80)	1.00
Wu b,2015 (<7h vs.7-8h)	1.06 (0.84, 1.35)	1.68
Haba-Rubio,2015 (<6h vs.7-8h)	0.95 (0.70, 1.29)	1.20
Min,2016 (≤5h vs.7h)	0.75 (0.59, 0.85)	2.23
Lin,2016 (<7h vs.6-7h)	1.54 (1.05, 2.47)	0.71
Rao,2016 (<7h vs.7-8h)	1.20 (0.80, 1.70)	0.87
Yoon,2016 (<6h vs.6-7h)	1.24 (1.18, 1.30)	4.00
Cole,2017 (<7h vs.7-8h)	0.75 (0.32, 1.77)	0.20
Suliga,2017 (≤6h vs.7-8h)	1.00 (0.95, 1.05)	3.98
Zohal,2017 (<6h vs.6-8h)	1.06 (0.43, 2.64)	0.18
Kim a,2018 (<6h vs.6-8h)	1.12 (1.05, 1.19)	3.84
Kim b,2018 (<6h vs.6-8h)	1.05 (1.00, 1.10)	4.00
van der Pal,2018 (<7h vs.7-8h)	0.96 (0.70, 1.30)	1.18
Titova,2018 (≤6h vs.7-8h)	1.08 (1.03, 1.13)	4.02
Ostadrahimi,2018 (<6h vs.6-9h)	0.97 (0.85, 1.10)	2.93
Qian,2019 (<7h vs.7-8h)	1.59 (1.10, 2.33)	0.88
Gaston a,2019 (<7h vs.7-9h)	1.23 (1.06, 1.42)	2.69
Gaston b,2019 (<7h vs.7-9h)	1.09 (1.02, 1.16)	3.82
Fan,2020 (<6h vs.6-9h)	1.37 (1.15, 1.62)	2.36
Xu,2020 (<6h vs.≥6h)	1.03 (1.01, 1.05)	4.19
Lu,2020 (<6h vs.7h)	1.57 (1.26, 1.95)	1.85
Ghazizadeh,2020 (<7h vs.6-8h)	1.27 (1.00, 2.00)	2.81
Wang,2021 (<7h vs.7-9h)	1.29 (1.06, 1.56)	2.11
Li,2021 (<7h vs.7-8h)	0.77 (0.54, 1.08)	1.00
Feng,2021 (<7h vs.7-8h)	1.16 (1.03, 1.31)	3.05
Katsuura-Kamano a,2021 (<6h vs.6-8h)	1.27 (1.12, 1.45)	2.92
Katsuura-Kamano b,2021 (<6h vs.6-8h)	1.13 (0.97, 1.33)	2.53
Subgroup, DL (I² = 79.1%, p = 0.000)	1.13 (1.08, 1.18)	85.03
Cohort		
Choi a,2011 (<6h vs.6-8h)	0.62 (0.24, 1.64)	0.16
Choi b,2011 (<6h vs.6-8h)	1.80 (1.06, 3.05)	0.49
Kim,2015 (<6h vs.6-8h)	1.41 (1.06, 1.88)	1.31
Li,2015 (≤6h vs.7-8h)	1.43 (1.18, 1.67)	2.60
Song,2016 (≤5.5h vs.7h)	1.22 (1.01, 1.50)	2.06
Itani,2017 (<5h vs.≥5h)	1.08 (1.03, 1.14)	3.97
Deng,2017 (<6h vs.6-8h)	1.08 (1.05, 1.13)	4.06
Wang,2021 (≥6h vs.7-8h)	3.04 (1.45, 6.35)	0.27
Subgroup, DL (I² = 74.9%, p = 0.000)	1.21 (1.10, 1.34)	14.97
Heterogeneity between groups: p = 0.187		
Overall, DL (I² = 78.5%, p = 0.000)	1.14 (1.10, 1.19)	100.00

NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

B

Study (Comparison)	OR/RR (95%)	% Weight
Cross-sectional		
Choi,2008 (≥9h vs.7h)	1.69 (1.17, 2.45)	1.54
Hall,2008 (>8h vs.7-8h)	1.81 (1.04, 3.15)	0.90
Najafian,2011 (≥9h vs.6-8h)	0.79 (0.66, 0.94)	2.90
Arora,2011 (≥9h vs.7-8h)	1.21 (1.10, 1.34)	3.34
Sabanayagam,2012 (≥9h vs.7h)	0.97 (0.69, 1.36)	1.70
Wu a,2012 (>8h vs.6-8h)	1.43 (0.82, 2.48)	0.90
Wu b,2012 (>8h vs.6-8h)	0.90 (0.32, 2.51)	0.31
Lee,2013 (≥9h vs.7h)	5.98 (1.41, 25.41)	0.17
Yoo,2013 (≥8h vs.6-8h)	4.89 (1.32, 18.13)	0.20
Chaput,2013 (≥9h vs.7-8h)	1.35 (0.83, 1.99)	1.25
Stefani,2013 (≥9h vs.7h)	1.31 (1.14, 1.51)	3.06
Ikeda,2014 (≥8h vs.6-7h)	1.12 (0.86, 1.46)	2.15
Yu,2014 (≥9h vs.≤7h)	1.18 (1.02, 1.37)	3.01
Saleh,2014 (9.7-11.8h vs.7.2-8.6h)	0.95 (0.66, 1.39)	1.53
Chang,2015 (>8h vs.7-8h)	1.44 (0.69, 2.98)	0.57
Wu a,2015 (≥10h vs.7-8h)	1.10 (0.98, 1.38)	2.83
Wu b,2015 (≥10h vs.7-8h)	1.33 (1.15, 1.54)	3.02
Haba-Rubio,2015 (≥8h vs.7-8h)	1.00 (0.67, 1.49)	1.41
Lim,2015 (>8h vs.<5h)	2.52 (0.83, 7.69)	0.27
Xiao,2016 (>8h vs.≤7h)	1.16 (1.03, 1.32)	3.18
Min,2016 (≥9h vs.7h)	1.31 (0.96, 1.78)	1.87
Lin,2016 (≥9h vs.7-8h)	1.12 (0.70, 1.82)	1.11
Rao,2016 (≥8h vs.7-8h)	1.40 (1.00, 2.10)	1.54
Yoon,2016 (≥10h vs.6-7h)	1.40 (1.25, 1.57)	3.25
Cole,2017 (>8h vs.7-8h)	0.86 (0.37, 2.01)	0.45
Suliga,2017 (≥8h vs.7-8h)	1.04 (0.95, 1.27)	3.03
Zohal,2017 (>8h vs.6-8h)	1.08 (0.74, 1.57)	1.50
Kim a,2018 (≥10h vs.6-8h)	1.28 (1.08, 1.50)	2.89
Kim b,2018 (≥10h vs.6-8h)	1.40 (1.24, 1.58)	3.22
van der Pal,2018 (≥8h vs.7-8h)	1.06 (0.80, 1.30)	2.30
Titova,2018 (≥9h vs.7-8h)	1.26 (1.14, 1.39)	3.34
Ostadrahimi,2018 (>9h vs.6-9h)	1.18 (1.05, 1.33)	3.22
Kim a,2019 (≥8h vs.<8h)	0.77 (0.48, 1.23)	1.15
Kim b,2019 (≥8h vs.<8h)	2.13 (1.04, 4.37)	0.59
Qian,2019 (≥11h vs.7-8h)	1.74 (1.23, 2.45)	1.67
Fan,2020 (>9h vs.6-9h)	1.12 (0.99, 1.26)	3.20
Lu,2020 (≥8h vs.7h)	1.32 (1.06, 1.65)	2.48
Ghazizadeh,2020 (>8h vs.6-8h)	0.99 (0.85, 1.16)	2.95
Wang,2021 (>9h vs.7-9h)	0.92 (0.84, 1.27)	2.57
Aryannejad,2021 (≥10h vs.≤5h)	0.76 (0.66, 0.87)	3.08
Li,2021 (≥8h vs.7-8h)	0.47 (0.23, 0.96)	0.60
Feng,2021 (≥8h vs.7-8h)	1.09 (0.98, 1.22)	3.28
Katsuura-Kamano a,2021 (≥8h vs.6-8h)	1.01 (0.91, 1.11)	3.34
Katsuura-Kamano b,2021 (≥8h vs.6-8h)	1.07 (0.93, 1.24)	3.04
Subgroup, DL (I² = 71.9%, p = 0.000)	1.15 (1.08, 1.22)	89.88
Cohort		
Choi a,2011 (≥10h vs.6-8h)	1.57 (0.61, 4.01)	0.37
Choi b,2011 (≥10h vs.6-8h)	1.66 (0.71, 3.88)	0.44
Kim,2015 (≥10h vs.6-8h)	0.68 (0.39, 1.17)	0.91
Li,2015 (≥8h vs.7-8h)	1.45 (1.09, 1.93)	2.01
Song,2016 (≥8.5h vs.7h)	1.24 (0.93, 1.66)	1.99
Deng,2017 (>8h vs.6-8h)	0.93 (0.88, 0.99)	3.55
Wang,2021 (≥8h vs.7-8h)	2.03 (1.14, 3.59)	0.85
Subgroup, DL (I² = 73.7%, p = 0.001)	1.21 (0.93, 1.58)	10.12
Heterogeneity between groups: p = 0.709		
Overall, DL (I² = 75.7%, p = 0.000)	1.15 (1.09, 1.23)	100.00

NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Figure 2. *Forest plots of associated with sleep duration and the risk of metabolic syndrome.* **A**. *Short sleep duration;* **B**. *Long sleep duration*

sleep quality evaluated by PSQI (OR = 1.76, 95% CI: 1.03–3.01, p = 0.039) and the risk of MetS. Our study failed to detect an association between overall sleep quality and MetS risk in different ethnicities (Tab. 3).

Publication bias and sensitivity analysis

The NOS scores of the 62 eligible studies were all ≥ 5 (Supplementary File — Tab. S1). No publication bias was found for the association between short and long sleep durations and the risk of MetS, which was identified by funnel plots and Begg's text (short sleep duration: p = 0.445; long sleep duration: p = 0.673) (Supplementary File — Fig. S1). Sensitivity analyses were conducted to confirm the robustness of the results.

Because the 7 original articles (8 studies) included subjects of more than one race [41, 45, 46, 54, 57, 75, 83], we conducted a sensitivity analysis by removing these studies. After excluding the 8 studies, the effect did not change substantially in short (OR = 1.13, 95% CI: 1.08–1.18, p < 0.001) and long sleep duration (OR = 1.15, 95% CI: 1.09–1.23, p < 0.001). In the study reported by Gaston et al. [75], the results were presented according to menopausal status and only provided data for short sleep duration. After excluding the study, the pooled OR still showed a stable association (short sleep duration: OR = 1.14, 95% CI: 1.09–1.19, p < 0.001). For the definition of MetS, the original data of 11 articles (13 studies) were adopted as non-internationally rec-

ognised criteria for MetS [36, 38, 42, 49, 52, 55, 74, 76, 78, 82, 84]. Subgroup analyses stratified by the criteria for MetS indicated significant associations between short and long sleep duration and the risk of MetS, which was defined by the modified NECP ATP-III criteria and the AHA/NHLBI criteria in cross-sectional studies (Supplementary File — Tab. S2 and S3). After deleting studies using non-internationally recognised criteria for MetS, the results did not present any major changes (short sleep duration: OR = 1.11, 95% CI: 1.07–1.16, p < 0.001; long sleep duration: OR = 1.15, 95% CI: 1.07–1.23, p < 0.001). Although the reference of sleep duration selected in the included studies was different, most of them were about 7–8 h, which presented a significant relationship between short (7–8 h: OR = 1.14, 95% CI: 1.05–1.24, p = 0.003) (Supplementary File — Tab. S2) and long sleep duration with MetS (7–8 h: OR = 1.14, 95% CI: 1.04–1.26, p = 0.005) (Supplementary File — Tab. S3).

Discussion

The correlation between sleep duration and the risk of MetS has been controversial [18–22]. Our meta-analysis included 62 studies with more than 870,000 participants. To the best of our knowledge, this is the most comprehensive study that provides quantitative pooled estimates of the associations of sleep quantity

Table 2. *Subgroup meta-analyses of cross-sectional and cohort studies*

Subgroups	Short sleep duration					Long sleep duration				
	N	OR/RR (95% CI)	p^a	I² (%)	p^b	N	OR/RR (95% CI)	p^a	I² (%)	p^b
Cross-sectional studies										
Ethnicity										
Caucasian	17	1.12 (1.04–1.20)	0.004	66.60	< 0.001	11	1.15 (1.08–1.22)	< 0.001	43.70	0.059
Asian	30	1.14 (1.07–1.21)	< 0.001	83.60	< 0.001	32	1.16 (1.07–1.24)	< 0.001	77.00	< 0.001
African	1	0.75 (0.32–1.76)	0.510	0.00	0.000	1	0.86 (0.37–2.00)	0.727	0.00	0.000
Sex										
Men	8	1.26 (1.11–1.42)	< 0.001	55.60	0.027	7	1.10 (1.03–1.18)	0.040	51.40	0.055
women	9	1.02 (0.93–1.13)	0.666	73.60	< 0.001	6	1.28 (1.19–1.38)	< 0.001	53.50	0.057
Study population										
Community	36	1.09 (1.04–1.13)	< 0.001	75.00	< 0.001	32	1.12 (1.05–1.19)	0.001	72.90	< 0.001
Hospital	5	1.31 (1.12–1.54)	0.001	64.50	0.024	5	1.41 (1.27–1.58)	< 0.001	28.90	0.229
Company or office	7	1.36 (1.20–1.55)	< 0.001	38.50	0.135	7	1.26 (1.05–1.51)	0.014	56.10	0.034
Source of sleep duration										
24 h	22	1.07 (1.01–1.13)	0.021	82.80	< 0.001	24	1.16 (1.08–1.25)	< 0.001	76.40	< 0.001
Night-time	23	1.24 (1.10–1.38)	< 0.001	73.90	< 0.001	18	1.11 (0.98–1.26)	0.100	61.50	< 0.001
Measurements of sleep duration										
Self-administered questionnaires	40	1.14 (1.08–1.19)	< 0.001	81.00	< 0.001	38	1.15 (1.08–1.23)	< 0.001	73.80	< 0.001
PSQI	5	2.37 (0.88–6.35)	0.087	77.00	0.002	3	2.78 (0.82–9.49)	0.103	78.30	0.010
Objective sleep measurements	3	0.92 (0.73–1.16)	0.474	0.00	0.876	3	0.96 (0.74–1.25)	0.768	0.00	0.000
Cohort studies										
Sex										
Men	2	1.08 (1.03–1.13)	0.004	21.30	0.260	1	1.57 (0.61–4.03)	0.348	0.00	0.000
Women	1	1.80 (1.06–3.05)	0.030	0.00	0.000	1	1.66 (0.71–3.89)	0.241	0.00	0.000
Study population										
Community	6	1.37 (1.09–1.73)	0.007	80.70	< 0.001	6	1.22 (0.88–1.69)	0.229	74.80	0.001
Hospital	1	1.22 (1.00–1.49)	0.049	0.00	0.000	1	1.24 (0.93–1.66)	0.146	0.00	0.000
Company or office	1	1.08 (1.03–1.14)	0.003	0.00	0.000					
Source of sleep duration										
24 h	3	1.09 (1.06–1.12)	< 0.001	38.00	0.199	2	0.93 (0.87–0.98)	0.011	19.00	0.267
Night-time	5	1.43 (1.12–1.82)	0.004	58.80	0.046	5	1.42 (1.18–1.71)	< 0.001	0.00	0.640

N — number; CI — confidence interval; OR — odds ratio (for cross-sectional studies); RR — risk ratio (for cohort study); PSQI — Pittsburgh Sleep Quality Index; p^a — p value for Z test; p^b — p value based on Q test for heterogeneity

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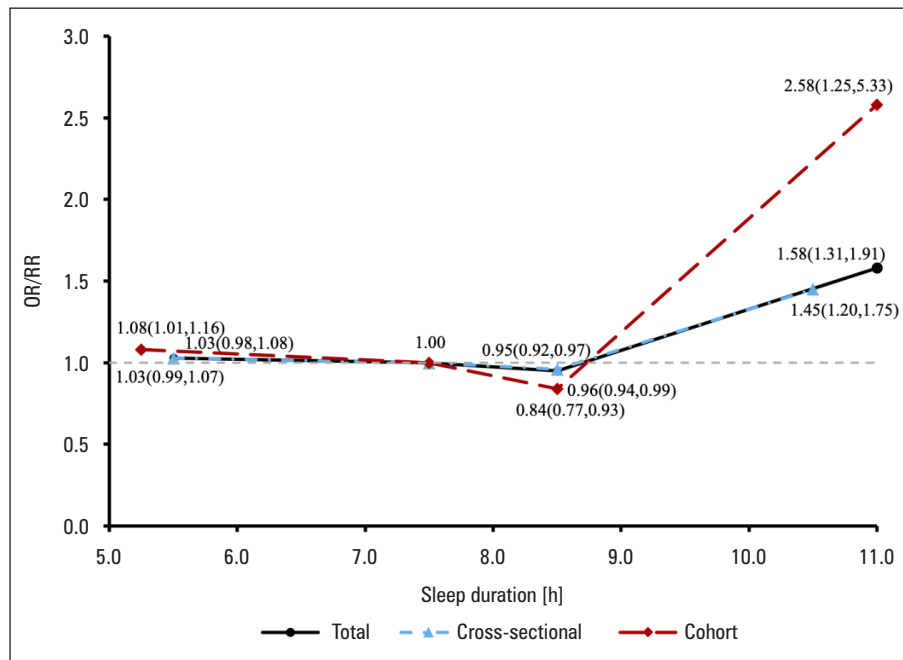
Figure 3. *The dose-response relationship between sleep duration and the risk of metabolic syndrome. OR — odds ratio; RR — relative risk*

Table 3. *Meta-analyses of sleep quality and the risk of metabolic syndrome (MetS)*

Variables	N	OR/RR (95% CI)	p[a]	I² (%)	p[b]
Overall sleep quality	8	1.46 (1.03–2.06)	0.033	78.30	< 0.001
Study design					
Cross-sectional	7	1.54 (1.02–2.32)	0.041	81.30	< 0.001
Cohort	1	1.20 (0.82–1.76)	0.349	0.00	0.000
Sleep complaints					
Use of sleep medication	2	1.32 (1.14–1.52)	< 0.001	0.00	0.625
Difficulty falling asleep	3	1.12 (1.06–1.19)	< 0.001	0.00	0.588
Difficulty maintaining sleep	3	1.20 (1.02–1.40)	0.028	67.20	0.047
Early morning awakening	1	1.07 (0.86–1.33)	0.536	0.00	0.000
Insomnia symptoms	2	1.05 (0.74–1.51)	0.771	70.80	0.064
Sleep-related breathing disorder	2	1.62 (1.25–2.11)	< 0.001	85.50	0.009
Subgroup analyses (cross-sectional)*					
Sex					
Men	2	1.31 (0.44–3.89)	0.625	88.30	0.003
Women	1	2.71 (1.45–5.07)	0.002	0.00	0.000
Ethnicity					
Caucasian	1	2.25 (0.70–7.21)	0.172	0.00	0.000
Asian	6	1.49 (0.97–2.30)	0.069	83.80	< 0.001
Measurements of sleep quality					
Self–administered questionnaires	1	0.95 (0.74–1.22)	0.688	0.00	0.000
PSQI	6	1.76 (1.03–3.01)	0.039	82.70	< 0.001

N — number; CI — confidence interval; OR — odds ratio (for cross-sectional studies); RR — risk ratio (for cohort study); PSQI — Pittsburgh Sleep Quality Index; p[a] — p value for Z test; p[b] — p value based on Q test for heterogeneity; *Subgroup analyses were conducted only in cross-sectional studies because there was only one cohort study included in the meta-analyses of sleep quality and the risk of MetS

and quality with the risk of MetS in adults, in which we updated the relationship between sleep duration and MetS, and evaluated the association between sleep quality and MetS for the included studies involving overall sleep quality or sleep disorders. Our findings demonstrate that short sleep duration is significantly associated with an increased risk of MetS, and long sleep duration is more likely to lead to the development of MetS, especially for 11 h. Additionally, 8.5 h presented a decreased risk for MetS. Furthermore, we found that poor sleep quality and sleep complaints were significantly positively correlated with MetS.

Previous meta-analyses have indicated that short sleep duration is related to an increased risk of MetS in cross-sectional and cohort studies [18, 21, 22], consistent with our findings. Several meta-analyses have shown that short sleep duration is associated with components of MetS, such as obesity, hypertension, and diabetes [86–89], which demonstrate a positive association between short sleep duration and the risk of MetS. Several possible underlying mechanisms may explain the correlation between short sleep duration and MetS. Short sleep duration is associated with reduced leptin and elevated ghrelin levels [90, 91], which leads to increased appetite, facilitates the development of obesity, and impairs glycaemic control [71, 92, 93]. Cortisol levels also increased with reduced sleep [94, 95], and elevated tumour necrosis factor alpha (TNF-α), interleukin (IL-6), and C-reactive protein (CRP) levels could partially explain insulin resistance and the rise in blood pressure [96–99]. Although the mechanisms of the inflammatory state that occurs after short sleep duration are still unclear, increased sympathetic activity is probably involved [100, 101].

The effects of long sleep duration remain uncertain [19, 20, 22]. Although the latest meta-analysis found an association between long sleep duration and MetS in cohort studies [23], the evidence of this study was limited, and the results may not be reliable because they mistakenly included cross-sectional studies as cohort studies in the meta-analysis. Additionally, the results of the latest original studies have been inconsistent [38, 78–80]. Our meta-analysis only observed a relationship between long sleep duration and MetS in cross-sectional studies. The exact mechanisms for the association between long sleep duration and MetS are not fully understood. Epidemiological studies have indicated that it is related to sleep fragmentation, fatigue, and depression [102–105], which could lead to MetS and increase the need for sleep. Increased levels of IL-6 and CRP have also been observed in long sleepers [99, 106, 107]. Additionally, individuals with long sleep duration may compress the waking time of physical activity and have a higher propensity toward unhealthy

behaviour [108, 109], thus influencing the overall well-being of adults, attributed to obesity, hypertension, and diabetes, all of which can trigger MetS [110, 111]. We theorise that habitual long sleep may elicit a proinflammatory metabolic state, combined with an unhealthy lifestyle, which may create optimal conditions for the development and progression of MetS. The definitions of short and long sleep duration vary in different studies, complicating the interpretation of the results. Therefore, whether short or long sleep duration is a real cause of MetS should be investigated and verified in other populations.

We conducted a restricted cubic spline random-effects meta-analysis to further explore the correlation between precise sleep duration and MetS. The previous meta-analysis reported by Ju et al. [22] indicated a "U-shaped" association between sleep duration and the risk of MetS assessed by the restricted cubic spline in 8 cross-sectional studies, in which ≤ 5 h, 5.5 h, 6 h, 6.5 h, 8 h, 8.5 h, 9 h, and 9.5 h positively related to the risk of MetS compared with 7 h per day. However, our findings demonstrated that sleep of 11 h was associated with an increased risk of developing MetS, and 8.5 h presented a decreased risk for MetS, consistent with the optimal sleep duration for adults recommended by the National Sleep Foundation (18–64 years: 7–9 h; ≥ 65 years: 7–8 h) [28]. Compared with the study by Ju et al. [22], our study involved more articles, including 16 cross-sectional studies and 6 cohort studies, which increased the credibility of the results. Although the restricted cubic spline analysis may strengthen the plausibility of a causal association, the estimates of risk in this approach are slightly less accurate than in the individual patient data meta-analyses because their calculations depend on the means, median, or midpoints of the sleep duration categories [22, 112, 113]. Different sleep duration categories may also partially contribute to the discrepancy in the results. Therefore, more original studies on the relationship between precise sleep duration and MetS should be conducted and included in subsequent meta-analysis updates to provide a scientific basis for the development of clear guidelines in the future.

We conducted comprehensive subgroup analyses of cross-sectional and cohort studies. Previous meta-analyses reported that no difference between sex was observed between sleep duration and MetS [19, 22]. However, we only observed a significant relationship between short sleep duration and increased risk of MetS in men, consistent with a recent meta-analysis by Xie et al. [18]. The potential mechanisms of sex subgroup differences in the relationship are unclear, but sex discrepancies in insulin sensitivity may partially explain this finding. Many aspects of energy balance

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and glucose metabolism have been regulated differently in men and women [114], and men are less sensitive to insulin than equally fit women [115]. In addition, related studies have also demonstrated that a lack of sleep is related to decreased insulin sensitivity and glucose tolerance in men [116]. The underlying mechanisms of sex subgroup differences require further investigation. For the measurements of sleep duration, previous meta-analyses found no distinction between sleep duration recorded by subjective or objective measurements and MetS [21]. However, in this study, we observed a significant association between either short or long sleep duration recorded by self-administered questionnaires and MetS in cross-sectional studies, while the association was not found in PSQI and objective measurements, which may be due to limited literature inclusion. Subjective and objective measurements are valuable methods for estimating sleep, assessing different and complementary dimensions of sleep [117, 118]. Although subjective measurements, such as questionnaires, may overestimate actual sleep duration [119, 120], it is inexpensive and allows the collection of information related to personal perception of sleep besides timing variables [118, 121], making them practical and widely used. Objective measurements such as polysomnography and accelerometry may provide more valid or accurate measurements, but the machinery may impede natural sleep and thus fail to reflect habitual sleep patterns [115, 122]. Considering the advantages and disadvantages of subjective and objective methods, their combination may be the most effective and practical method for population surveys. Moreover, it is worth mentioning that short sleep duration, defined by night-time or 24-h sleep duration, was associated with the risk of MetS in both cross-sectional and cohort studies. While a significant relationship was observed between MetS and long sleep duration defined by 24-h sleep in cross-sectional studies or long sleep duration defined by night-time sleep in cohort studies, only one of the published meta-analyses reported similar findings [18]. Human hormone levels and mechanisms were different during the day and night [123, 124], but most of the published studies did not distinguish sleep defined by night-time sleep duration and 24-h sleep duration. A meta-analysis reported by Yamada et al. indicated a "J-curve" relationship between daytime nap duration and MetS [125], which may confuse the potential association between sleep duration defined by 24-h sleep duration and MetS. Therefore, we suggest using sleep defined by night-time sleep duration to explore the relationship between sleep quality and quantity and MetS, as well as a separate analysis of nap time. In addition, sleep duration on weekdays and rest days should be reported separately.

We found that poor sleep quality emerged as an essential risk factor for MetS, observed only in cross-sectional studies and not found in cohort studies with one study included. Similar findings were detected in a meta-analysis reported by Lian et al. [24]. We also observed that sleep complaints, including use of medication, difficulty falling asleep, difficulty maintaining sleep, and sleep-related breathing disorders, were significantly correlated with MetS. Although the underlying biological mechanisms of the relationship between sleep quality and MetS are not known in detail, a growing body of research indicates that poor sleep quality and sleep complaints could affect energy regulation by upregulating appetite, thereby reducing insulin resistance [126], and alterations of neuroendocrine functioning and inflammation have also been found to be involved [99, 127]. Nevertheless, it remains possible that residual confounders result in an underestimation or overestimation of the association and should be interpreted with caution until further studies have been conducted.

We conducted a much more comprehensive meta-analysis of the relationship between sleep and the risk of MetS, which updated the relationship between sleep duration and MetS, and evaluated the association between sleep quality and MetS for the included studies involving overall sleep quality or sleep disorders, which has rarely been mentioned in previous studies. Our results may be more objective than the latest meta-analysis because they mistakenly treated the cross-sectional studies as cohort studies [23]. In addition, a restricted cubic spline random-effects meta-analysis was performed as a complementary investigation to evaluate the relationship between the exact sleep duration and MetS. Moreover, a series of sensitivity analyses were conducted to make the results more sensible and stable. However, our results should be interpreted with caution due to several limitations. First, most of the original studies included in this meta-analysis measured sleep duration and sleep quality using subjective measurements, and only 3 original studies used objective measurements such as polysomnography and accelerometry. Objective measurements may provide more valid or accurate results but often are not feasible in large prospective population studies. Therefore, a combination of subjective and objective measurements should be considered in future studies. Second, the categories of sleep duration and criteria of MetS varied across countries and studies, and were limited in translating the results of the restricted cubic spline analysis into practical recommendations for the public. Third, all included studies were assessed at a specific time point, and only 15 of them involved sleep quality, which may not sufficiently identify the sustained effect

of sleep problems in individuals with MetS. Therefore, investigations of the longitudinal effects of sleep problems, including quality and quantity, are the focus of future research. Despite these limitations, the findings of this meta-analysis provide the latest evidence to evaluate the effects of sleep duration and quality on MetS.

In conclusion, short sleep duration, long sleep duration, and poor sleep quality are associated with the risk of MetS. Additional original studies on the relationship between precise sleep duration and MetS should be conducted to provide a scientific basis for developing clear guidelines in the future.

Conflicts of interest

The authors declare that they have no competing interests.

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Author contributions

All authors certified that they participated in the conceptual design, data analysis, and manuscript writing to take public responsibility for it, and reviewed the final version of the manuscript and approved it for publication.

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