Review article

Association between sleep quality and metabolic syndrome: A systematic review and meta-analysis

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ABSTRACT

Sleep quality has been suggested to play an important role in development of metabolic syndrome (MetS). However, the results have been inconsistent. A systematic review of observational studies aimed to evaluate the association between sleep quality and MetS. A comprehensive search was conducted in PubMed and EMBASE. The pooled odd ratios (ORs) were calculated using random effects models. The construction of funnel plot was used to explore publication bias, with further application of Egger's test. 22 studies were included. The pooled finding showed that overall sleep quality had a significant positive association with MetS (OR 1.37, 95% CI 1.15–1.64), with substantial heterogeneity ($I^2 = 62.4\%$, $P < 0.1$). Similarly, the complaints of sleep, including difficulty in falling sleep (OR 1.18, 95% CI 1.05–1.33), difficulty in maintaining sleep (OR 1.15, 95% CI 1.02–1.30) and sleep inefficiency (OR 1.40, 95% CI 1.04–1.89) were proved to be associated with the risk of MetS. Our results indicated the overall sleep quality as well as sleep complaints have significant positive associations with MetS. Further studies based on a longitudinal design using validated tools that measure both objective and subjective components of sleep quality are needed to explore the causal relationship between sleep quality and MetS.

1. Introduction

Metabolic syndrome (MetS) is a cluster of metabolic abnormalities including dyslipidemia, obesity, elevated glucose and blood pressure (NCEP, 2001). It is reported that 35% of all adults suffer from MetS in the US (Aguilar et al., 2015). A recent meta-analysis reported by Li et al. identified MetS prevalence ranging between 22.0% and 26.9% in China (Li et al., 2016). It has been confirmed that cardiovascular diseases related to MetS were among the top 10 leading causes of death, and had mortality rates near to that of malignant cancer (Ford, 2005). The underlying etiology of MetS is multifactorial but not well known (Chen et al., 2016), with contributions from sedentary lifestyles and unhealthy dietary habits (Rao et al., 2016; van der Berg et al., 2016). Given the high prevalence and serious complications, early identifying and controlling the modified risk factors are crucial prevention methods against the development of MetS and its progression to cardiovascular diseases.

Epidemiological evidence has suggested that poor sleep health are associated with adverse outcomes such as cardiovascular disease (Massar et al., 2017; Tsai et al., 2015), MetS, and mental illness (Salo et al., 2012; Wang et al., 2017a). In general, there are two main estimating dimensions of sleep health including sleep duration and sleep quality (Buysse, 2014; Fatima et al., 2016). To some extent, sleep duration and sleep quality may overlap, but qualitative differences exist between them. Furthermore, previous studies have shown that correlations between sleep duration and sleep quality are poor (Pilcher et al., 1997), suggesting that the two separate sleep estimating domains may impose different impacts on health (Yannakoulia et al., 2017) (Stamatakis and Punjabi, 2010). Previous studies showed that the average self-reported sleep duration has decreased from over 8 h in the 1960s to 6.5 h in 2012 (Krueger and Friedman, 2009; Shankar et al., 2008). Data from a recent meta-analysis have confirmed that there is a U-shaped relationship between duration of sleep and MetS (Iftikhar et al., 2015). Although some clinical and epidemiological studies demonstrated the association between sleep quality and MetS, i.e. poor sleep quality characterized by sleep fragmentation was associated with impaired glucose metabolism, independent of sleep duration (Stamatakis and Punjabi, 2010), the investigations of these studies

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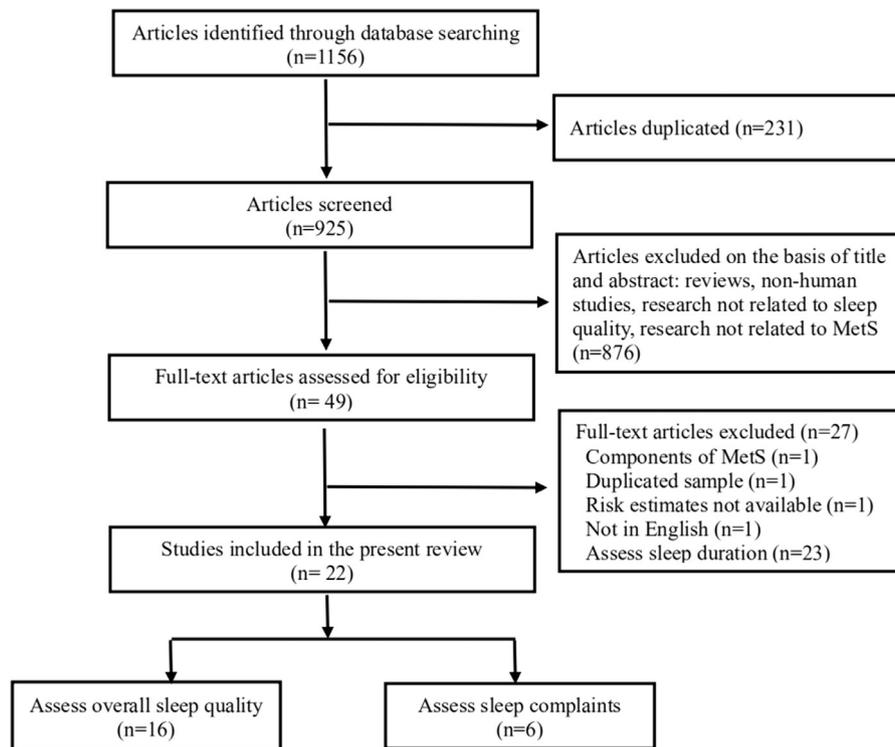 E-mail address: tangfangsdu@gmail.com (F. Tang).

Fig. 1. Flow chart of literature search and study selection.

have not reached a consensus. Additionally, no systematic review has yet investigated this association using meta-analysis technique.

In the present study, we conducted a systematic review and meta-analysis based on observational studies to, firstly, assess the association between the overall sleep quality and risk of MetS, and secondly, to examine the association between sleep complaints and risk of MetS.

2. Materials and methods

2.1. Search strategies

This report follows the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009). PRISMA checklist was shown in Table S1. A comprehensive literature search was conducted to identify articles available in Pubmed and EMBASE between the first available year and March 2018 using the following keywords: "sleep" and ("metabolic syndrome" or "MetS" or "MS" or "metabolic syndrome X" or "syndrome X" or "insulin resistance syndrome"). In addition, the reference lists of all identified relevant publications and reviews were searched manually.

2.2. Study selection

Studies were included if they met the following inclusion criteria: (1) The study used an observational study design. (2) The study reported sleep quality assessed either by objective measurements or an explicit questionnaire asking about sleep quality, including sleep latency, intermittent wakefulness, difficulties falling asleep, difficulties maintaining asleep, early morning awakening and other characteristics. Subjective aspects of sleep quality can be evaluated by the overall sleep quality scores or the explicit complaints. (3) The study reported usable risk estimates between sleep quality and MetS. (4) The study was published in English. Studies were excluded if the subjects with a condition known to disturb sleep (e.g., restless legs syndrome, obstructive sleep apnea).

2.3. Data extraction and quality assessment

Data from all eligible studies were independently extracted into a predesigned form by two authors (YL and FT). The following information were collected from each study: the name of first author, year of publication, study location, study design, sample size, number of participants, age and sex distribution, assessment of MetS and covariates adjusted in the multivariable analysis. Then, the quality of studies was assessed using eleven-score Agency for Healthcare Research and Quality (AHRQ) criteria for observational studies. Data extraction and quality assessment were performed by two authors independently. Disagreements were discussed and resolved by consulting a third author (QY).

2.4. Statistical analyses

We conducted meta-analyses for the overall sleep quality and sleep complaints separately including difficulty in falling sleep, difficulty in maintaining sleep, early morning awakening, awakening during the night and sleep inefficiency. The association between sleep quality with MetS was estimated by calculating pooled odd ratios (ORs) and 95% confidence intervals (CIs). The heterogeneity among studies was estimated by the Cochran Q test and I^2 statistic. The pooled ORs were calculated using random effects models (Dersimonian and Laird, 2015). Meta-regression analyses were conducted to explore the source of heterogeneity through assessing the association of the pooled estimates with potential covariates. Sensitivity analysis was conducted to test the stability of the results by excluding one study at a time (Wallace et al., 2009). The construction of funnel plot was used to explore publication bias, with further application of Egger's test (Egger et al., 1997). A *P* value of less than 0.05 on these tests was considered statistically significant for evidence of publication bias. All statistical analyses were performed using STATA/SE version 13.1 (Stata Corporation, College Station, TX, USA).

Table 1
Characteristics of the studies included in the present study.

Author, location	Number of MetS	Size of population	Proportion of men	Age (mean ± SD/range)	Sleep measure assessment	Definition of MetS	Confounding factors
Zohal et al, 2017, Iran CCS	330	1079	47.8%	40.1 ± 10.3	PSQI	NCEP ATP III	Age, gender, and body mass index
Okubo et al, 2014, Japan CCS	168	1481	37.1%	57.6 ± 13.9	PSQI	Committee to evaluate diagnostic standards for metabolic in Japan	Age, current drinking status, current smoking status, working hours per week, exercise habits and depression
Jennings et al, 2007, US CCS	41	210	57.0%	45.8 ± 6.0	PSQI	AHA/NHLBI	Age and sex
Chang et al, 2015, Taiwan CCS	218	890	92.6%	37.4 ± 7.73	PSQI	AHA/NHLBI	Age, low density lipoprotein cholesterol, smoking status, alcohol drinking habit, physical habitual exercise, snoring and type of shift work
Godin et al, 2017, France CCS	168	752	41.2%	31–51	PSQI	IDF	No
Kazman et al, 2012, US CCS	97	248	37.0%	44.6 ± 11.5	PSQI	AHA/NHLBI	Age and sex
Lajoie et al, 2015, Canada, CCS	NR	271	0%	42.1 ± 10.9	PSQI	Harmonized definition	Shift work
Lee et al, 2013, Korea, CCS	106	301	62.1%	50.8 ± 13.1	PSQI	NCEP ATP III	Gender, age, education, job, monthly average household income, smoking, daily alcohol intake, exercise habits, stress level, depressive mood and the other sleep parameters
Leineweber et al, 2003, Sweden CCS	45	295	0%	30–65	Karolinska sleep questionnaire	Two or more of the following components: fasting glucose level, blood pressure, dyslipidemia and obesity	Age, menopausal status, educational level, smoking, and exercise
Yoo and Franke, 2013, US CCS	35	106	NR	42.3 ± 8.4	PSQI	Modified AHA/NHLBI: assessment of obesity was modified using BMI of 30 kg/m or greater	Age, gender, smoking status, physical activity, burnout, depressive mood, and perceived stress
Mesas et al, 2014, Spain CCS	2297	10,342	50.1%	46.1 ± 3.4	Self-reported complaints	Harmonized definition	Sex, age, educational level, occupation-based social class, smoking, alcohol intake, binge drinking, coffee intake, sleep duration, energy intake, Mediterranean Diet Adherence Screener, physical activity and time watching TV, antihypertensive or lipid-lowering drug treatment
Hall et al, 2012, US CCS	104	340	0.0%	46–57	Polysomnography	NCEP ATP III	Race, menopausal status, educational attainment, marital status, health complaints, medications that affecting sleep, race, menopausal status, educational attainment, marital status, health complaints, medications that affecting sleep, smoking, alcohol use and regular exercise
Akbaraly et al, 2015, France CCS	977	6354	43.6%	65–97	Self-report questionnaire	NCEP ATP III	Age, sex, and study center, other sociodemographic, health behavior, and health status factors
Kielbasa et al, 2016, Poland CCS	160	261	50.2%	56.2 ± 16.6	Athens insomnia scale	IDF	Obstructive sleep apnea syndrome
Wang et al, 2017b, China CCS	2381	8017	51.7%	18–82	Athens insomnia scale	IDF	Age, gender, education degree, income, smoking, drinking, salt intake, physical activity and body mass index
Chen et al, 2015, Taiwan CCS	666	1359	49.9%	74.3 ± 6.0	Athens insomnia scale	NCEP ATP III	Age, sex, smoking, sedentary time, exercise, physical fitness and the components of MetS
Ikeda et al, 2014, Japan CCS	757	3936	40.4%	56. ± 16.3	Insomnia self-assessment inventory	JASSO	Sex, age class, smoking, drinking, exercise, skipping meals, eating between meals, eating out, and definitely feeling psychological stress
Lin et al, 2016, Taiwan CCS	880	4197	46.4%	47.9 ± 16.2	Insomnia self-assessment inventory	Harmonized definition	Sex, age, cigarette smoking, betel-nut chewing, and individual
Tsou et al, 2015, Taiwan CCS	405	1181	36.7%	74.4 ± 5.5	Athens insomnia scale	NCEP-ATP III	Age, sex, living status, smoking status, alcohol consumption, sedentary life-style, and depression status
Gonzaga et al, 2016, Brasil CCS	85	135	43.7%	12.7 ± 3.4	PSQI	NCEP ATPIII	Age and sex
Pulido-Arjona et al, 2018, US CCS	268	2779	45.8%	13.2 ± 2.2	BEARS questionnaire	Harmonized definition	Age, sexual maturity, body mass index, and cardiorespiratory fitness
Troxel et al, 2010, US CS	115	812	32.6%	59.0 ± 7.4	Insomnia symptom questionnaire	NCEP ATP III	Age, sex, race, marital status, smoking, alcohol consumption, sedentary lifestyle, and presence of clinically significant depressive symptoms

Note: NR: not reported; NCEP ATPIII: National Cholesterol Education Program's Adult Treatment Panel III, PSQI: Pittsburgh Sleep Quality Index, JASSO: Japan Society for the Study of Obesity, IDF: International diabetes federation, AHA/NHLBI: American Heart Association/National Heart Lung and Blood Institute, CSS: cross-sectional study, CS: cohort study.

Table 2

Methodological quality of included studies in the meta-analysis.

Item/Study	Define the source of information	List inclusion and exclusion criteria for exposed and unexposed subjects or refer to previous publications	Indicate time period used for identifying patients	Indicate whether or not subjects were consecutive if not population-based	Indicate if evaluators of subjective components of study were masked to other aspects of the status of the participants	Describe any assessments undertaken for quality assurance purposes	Explain any patient exclusions from analysis	Describe how confounding was assessed and/or controlled	If applicable, explain how missing data were handled in the analysis	Summarize patient response rates and completeness of data collection	Clarify what follow-up was expected and the percentage of patients for which incomplete data or follow-up was obtained
Zohal et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Okubo et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Jennings et al.	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Chang et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Godin et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Kazman et al.	Yes	Yes	Yes	No	No	Yes	No	Yes	No	No	No
Lajoie et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Lee et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Leineweber et al.	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
Yoo et al.	Yes	Yes	Yes	unclear	No	Yes	Yes	Yes	Yes	Yes	Yes
Mesas et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Hall et al.	Yes	Yes	Yes	unclear	No	Yes	Yes	Yes	Yes	No	No
Troxel et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Akbaraly et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Kielbasa et al.	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No
Wang et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Chen et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Iked et al.	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Lin et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Tsou et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Gonzaga et al.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Pulido-Arjona et al.	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No

3. Results

3.1. Study characteristics

A flow chart of studies identifying and selecting procedures were presented in Fig. 1. A total of 22 articles including 45,346 participants reported the association between sleep quality and MetS (Akbaraly et al., 2015; Chang et al., 2015; Chen et al., 2015; Godin et al., 2017; Gonzaga et al., 2016; Hall et al., 2012; Ikeda et al., 2014; Jennings et al., 2007; Kazman et al., 2012; Kielbasa et al., 2016; Lajoie et al., 2015; Lee et al., 2013; Leineweber et al., 2003; Lin et al., 2016; Mesas et al., 2014; Okubo et al., 2014; Pulidoarjona et al., 2018; Troxel et al., 2010; Tsou, 2015; Wang et al., 2017b; Yoo and Franke, 2013; Zohal et al., 2017). The characteristics of the articles were presented in Table 1. The quality assessment of these studies was shown in Table 2. Of these articles, one was longitudinal study, and 21 were cross-sectional studies. Of the included 22 studies, 9 were conducted in Asia, 7 were conducted in North America, 5 were conducted in Europe and one was conducted in South America.

The criteria for MetS varied between the studies. 8 studies reported MetS using the Third Report of the National Cholesterol Education Program's Adult Treatment Panel III (NCEP ATP III), 4 studies using harmonized definition, 3 studies using the International Diabetes Federation (IDF), 3 studies using American Heart Association/National Heart Lung and Blood Institute (AHA/NHLBI), one study using Japan Society for the Study of Obesity (JASSO), one study using the criteria according to Committee for the Criteria of MetS, one study using modified AHA/NHLBI and replaced waist circumference with body mass index and one study defining as the presence of two or more of the MetS components.

Sleep quality was assessed in different studies as overall sleep quality and its complaints, including difficulty in falling sleep, difficulty in maintaining sleep, early morning awakening, awakening during the night and sleep inefficiency. For the measurements of overall sleep quality, the Pittsburgh Sleep Quality Index (PSQI) was used in 10 studies, Athens Insomnia Scale in 3 studies, other insomnia self-assessment inventory in 2 studies and Karolinska Sleep Questionnaire in one study. In addition, difficulty in falling sleep were reported in 5 studies, difficulty in maintaining sleep in 4 studies, early morning awakening in 2 studies and awaking during the night in 2 studies. The objective methods for sleep assessment were rarely used, with just one study reporting sleep inefficiency the use of polysomnography.

3.2. Quantitative synthesis

3.2.1. The overall sleep quality and risk of metabolic syndrome

16 studies involving 20,153 participants examining the relationship between the overall sleep quality and MetS were included in the meta-analysis. The definition of poor sleep quality varied between studies, ranging from a cut off PSQI global score of 5–6, and most of included studies used global score >5 as the cut off. A higher score on the sleep quality index indicated a poorer sleep quality (range 0–9) for Karolinska Sleep Questionnaire. In addition, sleep quality involving insomnia were reported in 5 studies.

The random effects model was used because substantially significant between study heterogeneity was observed ($P < 0.1$, $I^2 = 62.4\%$). The pooled results showed that overall sleep quality had a significant positive association with MetS (OR 1.37, 95% CI 1.15–1.64) (Fig. 2).

No publication bias was detected according to Egger's test ($P = 0.074$). Visual inspection of the funnel plot did not identify substantial asymmetry (Fig. 3), which indicated no publication bias existed.

Sensitivity analysis was conducted by excluding one study at one time from each analysis to confirm the robustness of our analyses. Sensitivity analysis showed that the pooled ORs and 95% CIs did not

alter substantially by removing any one study (ranged from 1.10 to 1.74), confirming the stability of the present result (Fig. 4).

3.2.2. Sleep complaints and risk of metabolic syndrome

The pooled OR from 5 studies for the association between difficulty in falling sleep and MetS was 1.18 (95% CI 1.05–1.33), with no statistical heterogeneity ($P = 0.21$, $I^2 = 29.7\%$). Data pooled from 4 studies showed that the association between difficulty in maintaining sleep and MetS remained statistically significant (OR 1.15, 95% CI 1.02–1.30) and low heterogeneous. ($P = 0.23$, $I^2 = 29.7\%$). No significant association was found between early morning awakening and MetS (OR 1.05, 95% CI 0.93–1.19), with non-significant heterogeneity ($P = 0.83$, $I^2 = 0\%$). No significant association was found between awakening during the night and MetS (OR 1.20, 95% CI 0.91–1.58), with no heterogeneity ($P = 0.58$, $I^2 = 0\%$). The pooled results on the association between sleep complaints and metabolic syndrome were shown in Fig. 5. One study reported by Hall et al. investigated the association between sleep inefficiency and MetS using polysomnography. Adjusted analyses revealed that sleep inefficiency remained significantly associated with MetS (OR 1.40, 95% CI 1.04–1.89).

4. Discussion

In present study, we examined the association between sleep quality and MetS using meta-analysis technique. Our finding indicated that the overall sleep quality had a significant positive association with MetS. The complaints of sleep quality, including difficulty in falling sleep, difficulty in maintaining sleep and sleep inefficiency were all proved to be associated with the risk of MetS, with non-significant heterogeneity, except early morning awakening and awakening during the night. A large sample size with 45,346 participants and the absence of publication bias confer further strength to the finding of our study. The sensitivity analysis further confirmed the robustness of our conclusions.

Sleep health is a multidimensional concept. It is reported that there are various kinds of classification for sleep disruption, and sleep quality is one of the important estimating dimensions of sleep health (Buysse, 2014). In addition to quantitative indictors of sleep (sleep latency and sleep duration), sleep quality mainly refers to subjective perceptions of sleep, such as depth of sleep and general satisfaction with sleep. It is true that both sleep quality and sleep duration could influence health status, however, epidemiological studies indicated that sleep quality is better related to subjective well-being than sleep quantity (Pilcher et al., 1997). In addition, sleep quality seems to have a stronger effect than sleep duration on emotional state, behavior and cognitive function (Dewald et al., 2010). Since, the association between sleep duration and MetS has been fully proved in some recent systematic reviews (Iftikhar et al., 2015; Xi et al., 2014), the present study did not include the studies focusing solely on sleep duration. Previous meta-analyses have reported that poor sleep quality could increase the risk of obesity, hypertension, type 2 diabetes and dyslipidemia (Cappuccio et al., 2010; Fatima et al., 2016; Kruisbrink et al., 2017; Lo et al., 2018; Rahe et al., 2015). Considering that obesity, hypertension and impaired fasting glucose are components of MetS, it is natural that poor sleep quality was positively associated with MetS, and our study confirmed this point.

In the present review, the PSQI, Athens Insomnia Scale and Karolinska Sleep Questionnaire were used to assess the overall sleep quality. The PSQI is a recommended instrument to assess sleep quality with satisfactory reliability and validity, which covers a broad range of components related to sleep quality (Buysse et al., 1989; Mollayeva et al., 2016). Almost all included studies used the PSQI to measure sleep quality, which is similar to the observation in previous reviews on sleep quality (Sedov et al., 2017). Some studies performed the sleep quality assessment using the Athens Insomnia Scale and other insomnia self-assessment inventory. Only one study by Leineweber and colleagues assessed sleep quality using the Karolinska Sleep Questionnaire, which
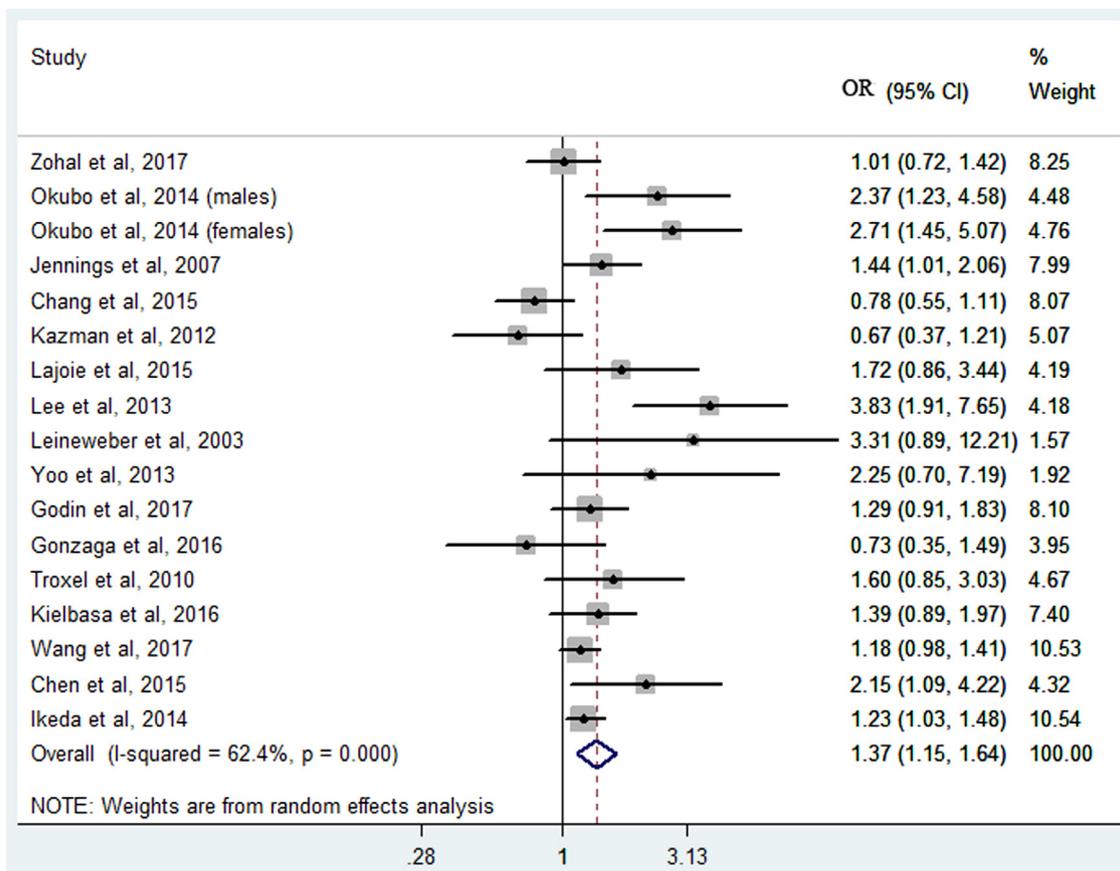
Fig. 2. Meta-analysis of the association between the overall sleep quality and risk of MetS.
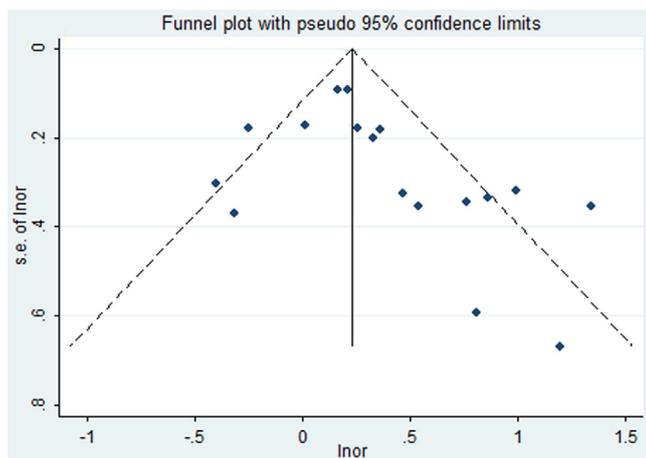

Fig. 3. Funnel plot showing symmetry of effect estimates for 16 studies assessing the association between sleep quality and MetS.

transformed the frequency of sleep disturbance into scores and provided definite cutoff points for poor sleep quality (Leineweber et al., 2003). Although different assessment tools were used, difficulties falling asleep and premature awakening are the common constructs of sleep quality, which match with some components of the PSQI. The use of objectively assessed indicators of poor sleep has been relatively less explored. Only one study used polysomnography to assess sleep inefficiency in this study. A recent research indicated that the PSQI global score is well correlated with objective sleep quality indexes obtained from polysomnography (Mollayeva et al., 2016). However, some subjective sleep quality component (such as feeling rested) might not be captured by objective measurements (Krystal and Edinger, 2008;

Werner et al., 2016). This indicates that it is of importance using adequate tools to assess sleep quality. Thus, validated tools that probe for both objective and subjective components of sleep quality would be the recommended approach for future studies.

Several potential biologic mechanisms may contribute to the relation of sleep quality and MetS. First, growing research indicated that poor-quality sleep as well as its complaints are associated with alterations in diurnal cortisol levels consistent with alteration of neuroendocrine functioning, in particular the hypothalamic-pituitary-adrenal (HPA) axis (Castro-Diehl et al., 2015; Massar et al., 2017). The HPA axis has a role in the development of insulin resistance and MetS (Ward et al., 2004). Second, a systematic review by Irwin confirmed the presence of association between sleep disturbance and markers of systemic inflammation such as C-reactive protein and interleukin-6 (Irwin et al., 2015). It is suggested that increased inflammation markers play an important role in the development of chronic diseases such as diabetes, and dyslipidemia (Kanagasabai and Ardern, 2015; Khansari et al., 2009). Third, sleep quality is thought to affect energy balance via up-regulation of appetite. Nocturnal awakening and arousal has been associated with altered leptin levels and leptin resistance, which plays a regulatory role in controlling appetite, elevated appetite could lead to an increase in body mass index and in turn increase insulin resistance (Mantzoros, 2006; Motivala et al., 2009; Pan and Kastin, 2014).

The findings from our study have significant implications for both public health and clinical practice. Given the findings of this study, as an important modifiable factor, sleep quality may be a point of particular interest for the prevention of MetS and its prognosis. Collaborative care may be most likely helpful to improve sleep quality including promoting sleep health education, creating enhanced health screening tools, providing early screening and prescribing individualized interventions for high risk population. Certainly, large-scale, randomized controlled trial assessing the effects of sleep quality
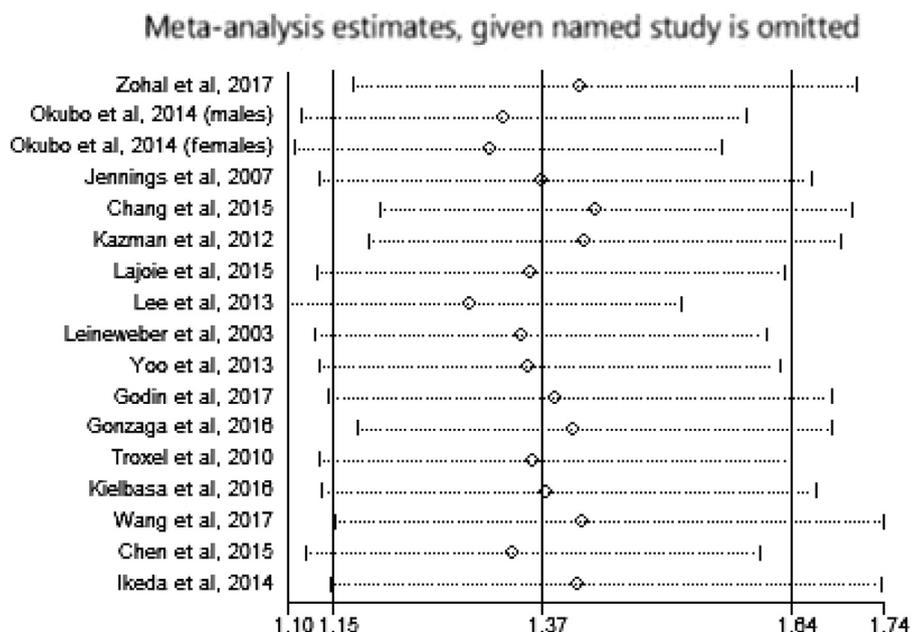
Fig. 4. Sensitivity analyses of the association between sleep quality and MetS by excluding one study at a time.
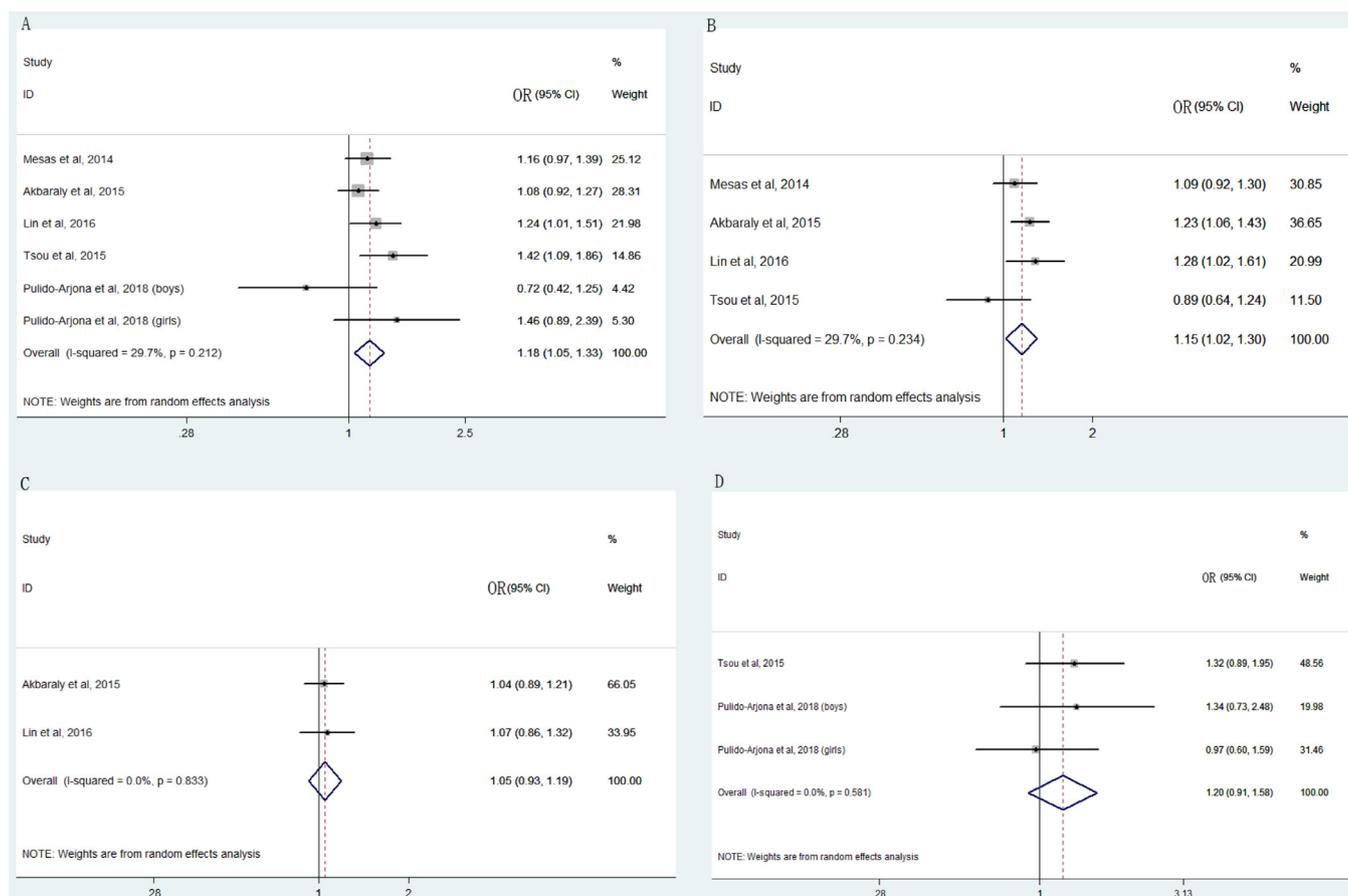

Fig. 5. Meta-analysis of the association between the sleep complaints and risk of MetS. A: difficulty in falling sleep and MetS, B: difficulty in maintaining sleep and MetS, C: early morning awakening and MetS, D: awakening during the night and MetS.

in improving glycemic control and preventing MetS, will be of particular interest. On the other hand, as revealed in previous studies, sleep quality is related to an increased risk of cardiovascular disease. MetS should be considered as an intermediated condition that frequently proceeds to the clinical manifestations of cardiovascular disease.

Therefore, we suggest that in individuals with poor sleep quality or insomnia, the cardiometabolic risk factors and MetS status should be carefully follow-up, and a potential targeted intervention could be advised.

Our results should be interpreted in light of certain limitations.

First, cross-sectional design was used in the majority of included studies, which may not give a causal relationship. Thus, well designed longitudinal studies are needed to further explore whether there is a cause-effect association between sleep quality and MetS, and randomized controlled trials are required to develop evidence-based screening and treatment models. Second, in the present meta-analysis, the residual confounding variables could not be fully controlled in all eligible studies. Almost all of the included studies were adjusted for age, gender and smoking. However, some of the studies did not consider well-defined risk factors for developing MetS such as food intake and physical activity. Further, prospective cohort studies with consideration of more potential confounders are required to examine the association between sleep quality and MetS risk. Third, the evidence of heterogeneity across studies was found in the meta-analysis. Meta-regression analyses were used to explore the source of heterogeneity through assessing the association of the pooled estimates with potential covariates. The following independent variables including publication year, size of sample, location and study design were introduced into the meta-regression model. However, these variables cannot explain the source of heterogeneity, suggesting that other unknown confounding variables might be the source of heterogeneity. Thus, the results of this analysis should be interpreted cautiously. Finally, as quality of sleep was only assessed in a specific time point in all studies, this may not sufficiently capture the sustained effect of poor sleep quality in individuals with MetS. Investigation of the change of sleep patterns and the longitudinal effects of sleep disturbance are important directions of future research. These limitations may impose a modest constraint on the interpretation of these findings, but they should not substantively undermine the internal validity of the study.

5. Conclusions

In summary, findings from the present review indicated that the overall sleep quality as well as some sleep complaints have positive influences on MetS. The findings of our study have significant implications for both public health and clinical practice. Future studies based on a longitudinal design using validated tools that measure both objective and subjective components of sleep quality are needed to explore the causal relationship between sleep quality and MetS.

Competing interests

The authors declare that they have no competing interests.

Author contributions

YL and FT conceived the study design; YL, QY and GP W searched and selected the articles, extracted, analyzed the data; YL drafted the manuscript. FT supervised the study and contributed the critical revision. All authors participated in the discussions, data analysis and result interpretation and approved the final version of the manuscript.

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Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2019.01.096.

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