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Systematic review

Effect of transcutaneous electrical acupoint stimulation on sleep quality: A systematic review and meta-analysis

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ABSTRACT

Introduction: Poor sleep quality may have a negative effect on health. Clinical studies have assessed the ability of transcutaneous electrical acupoint stimulation (TEAS) to improve sleep quality. This review aims to explore the efficacy and safety of TEAS to improve sleep quality, as well as the most promising application scenarios for TEAS.

Methods: Eight databases were searched from their inception to 25 March 2023 to identify randomized controlled trials (RCTs) of the effects of TEAS on sleep quality compared to sham stimulation or pharmacotherapy. In the meta-analysis, Pittsburgh sleep quality index (PSQI) global score was the main outcome. The methodological quality of each included article was assessed using the Cochrane Risk of Bias tool. Publication bias was assessed by funnel plots.

Results: A total of 16 studies involving 1555 participants met the inclusion criteria. Twelve RCTs had low or moderate risk of bias and four RCTs had high risk of bias. Overall, the findings indicated that TEAS was effective in improving sleep quality (mean difference (MD) -2.22; 95% confidence interval (CI) [-3.29, -1.15]; $p<0.0001$) with high heterogeneity ($I^2=92\%$; $p<0.00001$). Among different causes of insomnia, TEAS was found to be effective in patients with postoperative insomnia (MD -0.95; 95% CI [-1.62, -0.27]; $p=0.006$; $I^2=66\%$). Subgroup analyses showed that TEAS was more effective in middle-aged patients (MD -1.60; 95% CI [-2.14, -1.06]; $p<0.00001$; $I^2=0\%$), and Neiguan (PC6) and Hegu (LI4) were effective acupoints during the perioperative period (MD -1.45; 95% CI [-1.95, -0.95]; $p<0.00001$; $I^2=6\%$). Four studies reported adverse effects, none of which were serious.

Conclusions: TEAS could effectively improve postoperative insomnia. For postoperative insomnia, the effect of TEAS was more significant in middle-aged patients, and simultaneous stimulation of PC6 and LI4 was effective. However, due to the small number of included studies and variation in patient types, additional high-quality, large-scale, multicenter RCTs of the effect of TEAS on sleep quality are needed.

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1. Introduction

Sleep is an essential physiological process. Sufficient sleep enables the body to rest and recover, ensuring long-term regular bodily function. Insomnia is diagnosed in approximately 35–50% of adults annually [1] and the incidence is increasing [2]. The prevalence of short-term insomnia in the United States is reported to be 9.5%, with 20% of cases converting to chronic insomnia; most chronic insomnia patients experience the condition for up to 4 years [2]. Sleep deprivation can negatively affect health, causing symptoms such as headache, fatigue,

Abbreviations: TEAS, transcutaneous electrical acupoint stimulation; RCT, randomized controlled trial; PSQI, pittsburgh sleep quality index; MD, mean difference; CI, confidence interval; TCM, traditional Chinese medicine; TENS, transcutaneous electrical nerve stimulation.

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and gastrointestinal discomfort, and leading to severe illnesses such as reduced immunity and cardiovascular disease [3]. Chronic sleep deprivation negatively affects the brain, impairing cognitive functions such as memory, concentration, and judgment [4]. Sleep deprivation is also associated with mood disorders, anxiety, depression, and other mental illnesses [5,6]. Therefore, clinical efforts are needed to address poor sleep quality or sleep disorders.

Many factors can induce a decline in sleep quality. Studies have found that exposure to blue light at night or the use of light-emitting electronic devices suppresses melatonin and delays one's biological clock [7]. Exposure to light while sleeping can cause a circadian rhythm reset response [8]. Stress can also lead to disturbances in falling asleep and staying asleep, with risks for shift work disorders, depression, and anxiety [9]. Hormonal changes are another factor that may affect sleep quality, especially in women. Hormonal fluctuations during menstruation, pregnancy, and menopause can disrupt sleep and lead to sleep disorders [10,11]. Sleep disturbance is also a common complication of diseases such as Alzheimer's disease [12], chronic obstructive pulmonary disease [13], and breast cancer [14], which may relate to disease treatment. It is thus clear that many environmental, psychological, and physiological factors can influence sleep quality.

Due to the complicated causes of poor sleep quality, the current mainstream clinical approach to improving sleep quality is the use of symptom-relieving medications such as benzodiazepines, antidepressants, and antihistamines [15,16]. However, these medications may be addictive and impair cognitive function [17], negatively impacting patients' physical and mental health and quality of life. As a result, non-pharmacological approaches with fewer side effects, such as cognitive behavioral therapy [18] and light therapy [19], are receiving increased research attention. However, cognitive behavioral therapy is costly, time-consuming, resource intensive, and does not work for all patients [20], while light therapy shows poor patient compliance and acceptability as an intervention [21].

Another non-pharmacological approach that has attracted attention for its ability to improve sleep quality is acupuncture [22], which is based on traditional Chinese medicine (TCM) theory. Acupuncture at specific points can increase serotonin and aminobutyric acid levels and reduce glutamate acid, thus improving central inhibitory function and sleep quality. Electroacupuncture [23] is a method derived from acupuncture that involves connecting acupuncture needles to a micro-electric stimulator. By adjusting the current pattern to simulate manual acupuncture, it can have the effect of improving sleep quality. However, as most patients are afraid of needle insertion, patient uptake of the above two treatments is poor. Furthermore, these two therapies require physicians to have sufficient knowledge and skills.

Transcutaneous electrical acupoint stimulation (TEAS) [24] is a method of regulating the physiological functions of the human body through electrical stimulation of acupoints. It combines acupuncture theory with transcutaneous electrical nerve stimulation (TENS) technology and can be used as a supplement or alternative to acupuncture [25]. TEAS uses the gate control mechanism of TENS to stimulate the acupuncture points of TCM to achieve the effects of reconciling qi and blood, improving blocked meridians, and restoring the body's balance. However, the underlying mechanisms of this method remain unclear [26]. TEAS is frequently used for analgesia, sedation, delirium prevention, and the prevention of postoperative nausea and vomiting [27–29]. Electroacupuncture and TEAS are analogous in that they both use similar peripheral and central mechanisms of action [30]. TEAS retains the stimulating characteristics of electroacupuncture, but feels relatively gentle and comfortable to patients. In this way, the shortcomings of acupuncture and electroacupuncture are overcome [31]. Since TEAS is non-invasive, it does not need to be performed by a trained professional. After training, patients can independently perform TEAS at home to achieve autonomy. Hence, TEAS may be an effective and acceptable treatment for sleep problems.

There are several reports of the use of TEAS to relieve insomnia and improve sleep quality [24,32]. However, studies of TEAS for insomnia include different patient types and implementation methods and report varying results. However, as interest in TEAS progresses, new randomized controlled trials (RCTs) have been conducted.

Despite the abundance of clinical studies on TEAS to improve sleep quality, there is no summary of their clinical effectiveness and safety. Therefore, this study aims to summarize and analyze existing clinical studies on TEAS for sleep problems through a systematic review and meta-analysis. By quantitatively evaluating the effects of TEAS for different patient types, this study can provide a reliable basis to inform clinical practice.

2. Methods

This systematic review and meta-analysis were conducted following the guidance of the Cochrane Handbook for Systematic Reviews of Interventions 2nd edition [33] and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines [34]. This review and meta-analysis are registered with PROSPERO (CRD42023440453).

2.1. Search Method

To identify relevant studies, we searched the following English and Chinese databases from inception to March 25, 2023: 1) PubMed; 2) Web of Science; 3) MEDLINE; 4) EMBASE; 5) Cochrane Reviews and Trials; 6) China National Knowledge Infrastructure; 7) WANFANG Database; and 8) Chongqing VIP Chinese Science and Technology Periodical database. To ensure a comprehensive search, we expanded the scope to determine the search keywords. The English search terms (based on the medical subject headings thesaurus) were (sleep OR insomnia OR 'quality of life') and (electric stimulation therapy) and (acupuncture points). The Chinese search strategy was adjusted for Chinese medical terms and their usage in the literature. The search strategy consisted of the intersection of Chinese medical terms related to the problem ('sleep' OR 'falling asleep and sleeping disorders' OR 'quality of life') and the intervention ('acupoint' OR 'meridian') and ('electric stimulation therapy'). Detailed search strategies for the above eight databases are provided in Appendix A. We also searched the reference lists of the retrieved studies and systematic reviews, and contacted experts in the field for information on ongoing and completed trials. The search was not limited by language or year of publication.

2.2. Study selection criteria

Studies were included for qualitative synthesis if the following criteria were met: (1) TEAS was the only clinical intervention; (2) sham stimulus therapy or pharmacotherapy was used as a control; (3) the study design was an RCT; (4) the Pittsburgh Sleep Quality Index (PSQI) was used to evaluate sleep quality; and (5) participants had a global PSQI score$>$ 5 [35] at the time of sleep disturbance. There were no restrictions on the age of the subject, diagnosis of sleep disorder, cause of sleep disorder, comorbidities, etc. Any disagreements over the eligibility of studies were resolved through discussion and consensus of all three authors.

2.3. Quality assessment

The quality of the included studies was appraised by two independent reviewers. RCTs were assessed for risk of bias using the revised version of the Cochrane Risk of Bias Tool for RCTs. Any discrepancies in quality assessment between the two authors were resolved by a third reviewer or by consensus of all three authors.

2.4. Data extraction

For each included study, the following data were extracted: source, design, diagnosis, ethnicity, age, sample size, intervention, control, and outcome at different timepoints. Data were extracted by one author and confirmed by the other two authors.

2.5. Data synthesis

The aim of this study was to investigate the effectiveness of TEAS for improving sleep quality and to provide recommendations for future applications. For the meta-analysis, the mean and standard deviation of the baseline and post-treatment PSQI scores were extracted from each study and the mean difference (MD) was calculated by subtracting the baseline PSQI score from the post-treatment PSQI score. Studies were excluded if they did not have sufficient information to calculate the MD. Review Manager 5.4 software was used for data analysis. Effect sizes were reported as pooled MD with 95% confidence intervals (CIs). The heterogeneity of the effect size estimates across the studies was quantified using the I^2 statistic. If $I^2<50\%$, a fixed-effects model was used; if $I^2>50\%$, a random-effects model was used. When heterogeneity was high, comparisons were carried out by means of subgroup analysis.

3. Results

3.1. Study Characteristics

The initial search identified a total of 1227 articles (Fig. 1.). After removal of duplicates, 413 articles were exported to EndNote20 reference manager software. The titles and abstracts were then independently screened according to the inclusion and exclusion criteria by two reviewers, resulting in 20 articles being subjected to full-text assessment. Of these, four articles were excluded for the following reasons: one study had no calculable PSQI score for the experimental and control groups [36], two studies were Master's theses [37,38] duplicated by two included journal articles, and one study only had an English abstract without available data [39]. Ultimately, 16 articles were included in the qualitative synthesis and review.

The characteristics of the included studies are presented in Table 1. The included studies were conducted between 2014 and 2023 and included 1555 participants. One of the 16 studies was conducted in Iran [40] and the rest were conducted in China. Regarding the study population, seven studies involved patients with insomnia after surgical treatment [41–47], two involved patients with depressive insomnia [48, 49], one involved nurses with insomnia caused by shift work [40], and

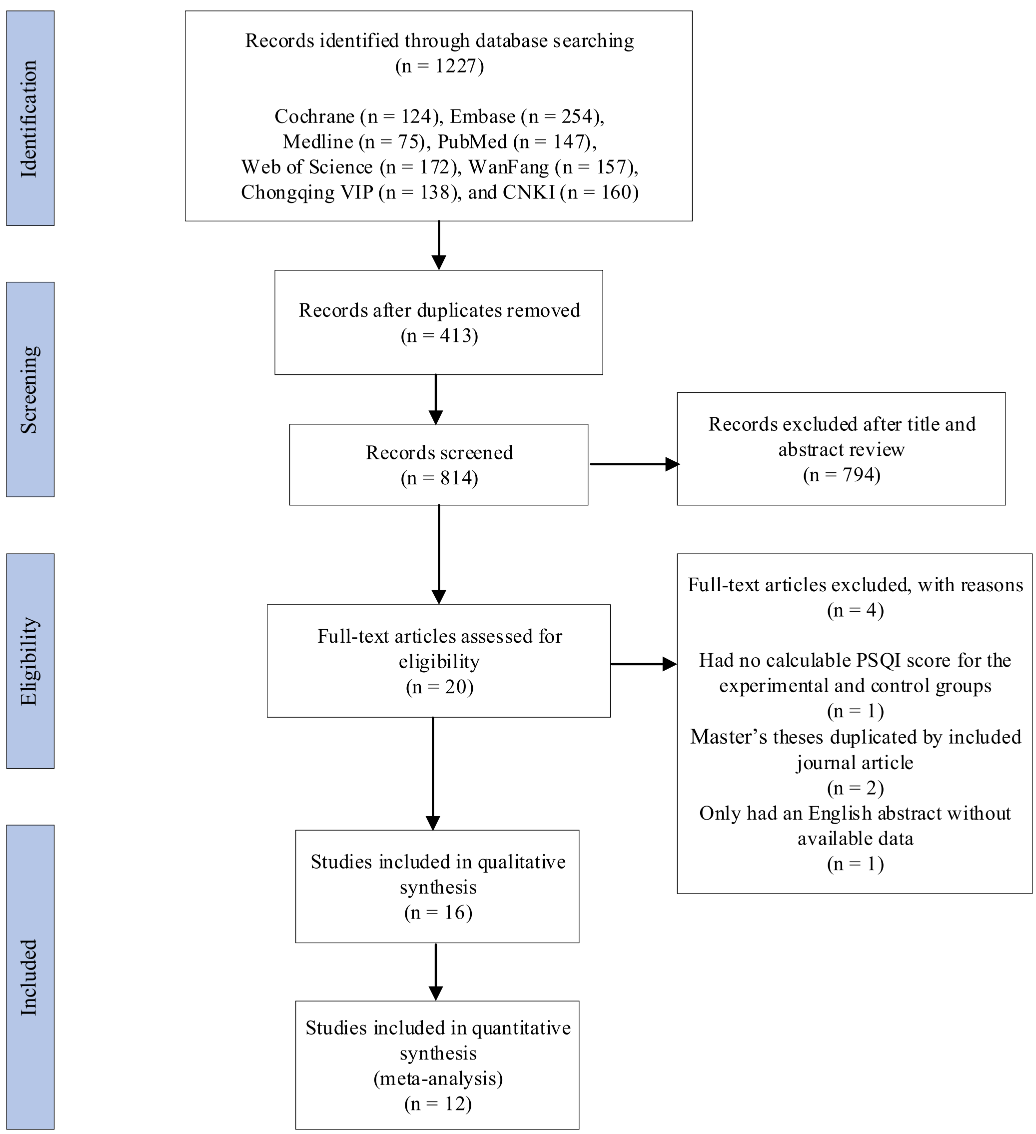

Fig. 1. PRISMA flow diagram for study selection.

Table 1
Summary of randomized controlled trials of transcutaneous electrical acupoint stimulation for patients with insomnia

Source	Design	Diagnosis	Ethnicity	Age (mean ± SD, years)	Sample size (male/female)	Intervention	Control	Outcome (timepoints)
Zhang et al. 2023 [49]	RCT	Mild-to-moderate depression	Chinese	T: 39.9 ±13.7 C: 40.6 ±12.9	T: 233 (70/163) C: 235 (65/170)	TEAS treatment Acupoint: EX-HN3, DU20, CO12, CO15 Duration: 30min/session Frequency: 2 session/day Length: 8 weeks	Escitalopram treatment General dose: 10 mg/day Maximum dose: 20mg/day Length: 8 weeks	PSQI (day 0; weeks 4, 8, and 12 after the start of treatment)
You 2021 [50]	RCT	Methamphetamine use disorder protracted insomnia	Chinese	T: 37.13 ±7.34 C: 37.33 ±8.83	T: 30 (22/8) C: 30 (24/6)	TEAS treatment Acupoint: EX-HN3, HT7, SP6, BL62, KI6, EX-HN0 Duration: 45min/session Frequency: 1 session/day; 5 day/week Length: 28 days	Eszopiclone treatment Dose: 3 mg/day, gradually tapered until discontinuation Length: 28 days	PSQI (day 0; 1 day and 4 weeks after treatment ends)
Wu 2021 [48]	RCT	Adult depression	Chinese	T: 32.5 ±13.351 C: 31 ±10.312	T: 30 (10/20) C: 30 (13/17)	TEAS treatment Acupoint: EX-HN3, DU20 Duration: 30min/session Frequency: 2 session/day Length: 4 weeks	Escitalopram oxalate treatment Dose: 10-20 mg/day Length: 4 weeks	PSQI (day 0; after treatment)
Tang et al. 2014 [55]	RCT	Post-stroke insomnia	Chinese	T: 63±11 C: 65±10	T: 40 (22/18) C: 40 (21/19)	TEAS treatment Acupoint: BL23, DU14 Duration: 30min/session Frequency: 1 session/day Length: 30 days	Estazolam treatment Dose: 1 mg/day Length: 30 days	PSQI (day 0; day 2 after treatment)
Wang et al. 2022 [54]	RCT	Mild cognitive impairment	Chinese	T: 66.9 ±3.66 C: 67.0 ±4.36	T: 25 (5/20) C: 27 (4/23)	TEAS treatment Acupoint: CO15, CO10 Duration: 30 min/session Frequency: 2 session/day; 5 day/week Length: 24 weeks	Sham stimulation treatment Acupoint: SF3, SF4,5 Duration: 30 min/session Frequency: 2 session/day; 5 day/ week Length: 24 weeks	PSQI (day 0; after treatment)
He et al. 2020 [53]	RCT	Glomus hysteria	Chinese	Total: 45.17 ±7.26	T: 30 C: 30	TEAS treatment Acupoint: LU11 Duration: 30 min/session Frequency: 2 session/day Length: 4 weeks	Sham stimulation treatment Acupoint: 1-2 cm beside LU11 Duration: 30 min/session Frequency: 2 session/day Length: 4 weeks	PSQI (day 0; after treatment)
Chang 2020 [42]	RCT	Patients undergoing thoracoscopic surgery	Chinese	T: 56.3±6.2 C: 53.3±5.9	T: 30 (16/14) C: 30 (17/13)	TEAS treatment Acupoint: HT7, PC6 Duration: 30 min/session Frequency: the day before surgery; during surgery; the first, second and third days after surgery	Sham electroacupuncture treatment Acupoint: HT7, PC6 Duration: 30 min/session Frequency: the day before surgery; during surgery; the first, second and third days after surgery	PSQI (day 0; days 1, 2, 3, and 6 after surgery)
Zadeh et al. 2018 [40]	RCT	Shift working nurses with sleep quality problems	Iranian	Total: 34.16 ±11.34	T: 12 (5/7) C: 12 (4/8)	TEAS treatment Acupoint: SP6, HT7, LI4 Duration: 5 min/session Frequency: 2 session/week Length: 4 weeks	Sham stimulation treatment Acupoint: 1.5-2 cm beside SP6, HT7, LI4 Duration: 5 min/session Frequency: 2 session/week Length: 4 weeks	PSQI (day 0; after treatment)

(continued on next page)

Table 1 (*continued*)

Source	Design	Diagnosis	Ethnicity	Age (mean ± SD, years)	Sample size (male/ female)	Intervention	Control	Outcome (timepoints)
Guo et al. 2018 [52]	RCT	Sleep Disorders in Chronic Fatigue	Chinese	T: 39±10 C: 38±9	T: 46 (18/ 28) C: 43 (17/ 26)	TEAS treatment Acupoint: DU14, DU4, RN8, RN4 Duration: 30 min/ session Frequency: 5 session/ week Length: 4 weeks Current intensity: 12 ±2mA	Sham stimulation treatment Acupoint: DU14, DU4, RN8, RN4 Duration: 30 min/session Frequency: 5 session/week Length: 4 weeks Current intensity: 1mA	PSQI (day 0; after treatment)
Liao 2017 [51]	RCT	Methamphetamine dependence protracted insomnia	Chinese	T: 35.23 ±7.798 C: 33.30 ±7.512	T: 30 C: 30	TEAS treatment Acupoint: BL15, BL18, BL20, BL23 Duration: 1h/session Frequency: 5 session/ week Length: 28 days	Sham stimulation treatment Acupoint: BL15, BL18, BL20, BL23 Duration: 1h/session Frequency: 5 session/week Length: 28 days Instrument did not regulate current.	PSQI (day 0; day 1 after treatment)
Wei et al. 2021 [46]	RCT	Elderly patients undergoing hip replacement	Chinese	T: 70.0 (67.0,75.0) C: 71.5 (69.0,76.7)	T: 50 (17/ 33) C: 52 (22/ 30)	TEAS treatment Acupoint: HT7, PC6 Duration: 30 min/ session Frequency: during surgery; the first, second and third days after surgery	Sham stimulation treatment Acupoint: HT7, PC6 Duration: 30 min/session Frequency: during surgery; the first, second and third days after surgery The instrument is not powered on.	PSQI (day 0; day 3 after surgery)
Qin 2021 [44]	RCT	Elderly patients undergoing laparoscopic surgery	Chinese	T: 65.55 ±4.06 C: 65.50 ±3.40	T: 20 (11/ 9) C: 20 (9/ 11)	TEAS treatment Acupoint: PC6, ST36, SP6 Frequency: during surgery	Sham stimulation treatment Acupoint: PC6, ST36, SP6 Frequency: during surgery The instrument is not powered on.	PSQI (day 0; day 3 after surgery)
Chang et al. 2021 [41]	RCT	Elderly patients with sleep disorder undergoing total hip arthroplasty	Chinese	T: 71.2±5.0 C: 70.1±5.0	T: 44 (24/ 20) C: 41 (26/ 15)	TEAS treatment Acupoint: PC6, LI4 Duration: 30 min/ session Frequency: during surgery; the first, second and third days after surgery	Sham stimulation treatment Acupoint: PC6, LI4 Duration: 30 min/session Frequency: during surgery; the first, second and third days after surgery The instrument is not powered on.	PSQI (day 0; day of discharge; 1 month after surgery)
Li et al. 2020 [43]	RCT	Elderly postoperative patients with gynecological tumors	Chinese	T: 67.6±7.6 C: 67.0±7.2	T: 40 C: 40	TEAS treatment Acupoint: PC6, LI4 Frequency: during surgery	Sham stimulation treatment Acupoint: PC6, LI4 Frequency: during surgery The instrument is not powered on.	PSQI (day 0; days 3 and 7 after surgery; the day before discharge)
Wang et al. 2020 [45]	RCT	Patients after radical resection of esophageal cancer	Chinese	T: 47±8 C1: 48±8 C2: 48±7	T: 50 (34/ 16) C1: 50 (33/17) C2: 50 (35/15)	TEAS treatment Acupoint: PC6, LI4 Frequency: during surgery	C1: Sham stimulation treatment; acupoint: PC6, LI4; frequency: during surgery; the instrument is not powered on. C2: Sham stimulation treatment; acupoint: non-point; frequency: during surgery	PSQI (day 0; days 3 and 7 after surgery)
Wang et al. 2023 [47]	RCT	Patients Undergoing Laparoscopic Gastrointestinal Tumor Surgery	Chinese	T: 58.20 ±7.90 C: 60.44 ±9.64	T: 40 C: 43	TEAS treatment Acupoint: HT7, PC6, ST36 Duration: 30 min/ session Frequency: the night before surgery, the night of the surgery, the first night after surgery	Sham stimulation treatment Acupoint: HT7, PC6, ST36 Duration: 30 min/session Frequency: the night before surgery, the night of the surgery, the first night after surgery The instrument is not powered on.	PSQI (day 0; day 3 after surgery)

TEAS: transcutaneous electrical acupoint stimulation; PSQI: Pittsburgh sleep quality index; RCT: randomized controlled trial randomized controlled trial; Day 0: baseline, when PSQI > 5.

six involved patients with insomnia complications due to different diseases, including protracted methamphetamine use disorder [50], protracted methamphetamine dependence [51], chronic fatigue [52], glomus hysteria [53], mild cognitive impairment [54], and post-stroke [55]. Wang et al.'s study [45], Tang et al.'s study [55], and six studies of patients with postoperative insomnia [41–44,46,47] involved elderly patients with an average age > 50 years. The other studies involved middle-aged participants ranging in age from 30 and 50 years. Of the seven studies involving patients with postoperative insomnia, one study focused on gynecologic oncology [43] and so all participants were female. The interventions included in the studies were TEAS with acupoints covering ordinary acupoints [40–46,50–53,55], cranial-auricular acupoints [48,49], or auricular vagus nerve acupoints [54]. The control interventions were sham stimulation [40–47,51–54] or drug treatment (escitalopram [48,49], eszopiclone [50], estazolam [55]). Twelve studies compared TEAS with sham stimulation. In terms of treatment duration, three studies were for 24 weeks [54], 8 weeks [49], and 30 days [55] respectively, six studies were for 4 weeks [40,48,50–53], three studies were intraoperative only [43–45], and one study was the night before surgery, the night of the surgery, and the first night after surgery [47]. Two studies were conducted during surgery and on postoperative days 1 to 3 [41,46], and one study also included the day before surgery [42]. In terms of the intervention acupoints and electricity supply in the control group, six studies used the same acupoints but with non-energized electrodes [41,43–47], three studies used the same acupoints but with a weak current [42,51,52], three studies used non-acupoints with energized electrodes [40,45,53], and one study acted on non-effective acupoints with energized electrodes [54]. All included studies used PSQI to assess sleep quality. The four studies using drug treatment as the control condition reported no significant group differences [48–50,55]. The 12 studies using sham stimulation as the control condition reported significant group differences within 1 week after treatment, with two studies also showing significant group differences at 1-month follow-up [41,43].

3.2. Risk of bias

Two of the 16 RCTs had a low risk of bias in all seven aspects. Eight RCTs were rated as having an unclear risk of bias in the aspects of "selection bias", "performance bias", and "detection bias". Only five studies were rated to have a low risk of selection bias (allocation concealment), and the rest were rated as having an unclear risk of bias. For performance bias and detection bias, four studies with no placebo/ or sham control for either intervention were rated as high risk, and the remaining 10 studies were unclear. All studies had low bias in terms of selection bias (random sequence generation), attrition bias, reporting bias, and other bias (Fig. 2.).

3.3. Acupuncture points

The 16 studies used a total of 22 acupuncture points. In the included studies, the number of acupoints used per participant ranged from 1 to 6 (Table 2). The most commonly used acupuncture points were Neiguan (PC6) in >35% of studies, Shenmen (HT7) and Hegu (LI4) in 25–35% of studies, and Yintang (EX-HN3) and Sanyinjiao (SP6) in 15–25% of studies. The following points were used in 10–15% of the studies (sometimes used): Baihui (DU20), Shenshu (BL23), Daizhui (DU14), Cavum conchae heart (CO15), Zusanli (ST36). The following points were used in <10% of studies (rarely used): Cymba conchae kidney (CO10), Cymba conchae liver (CO12), Shenmai (BL62), Zhaohai (KI6),

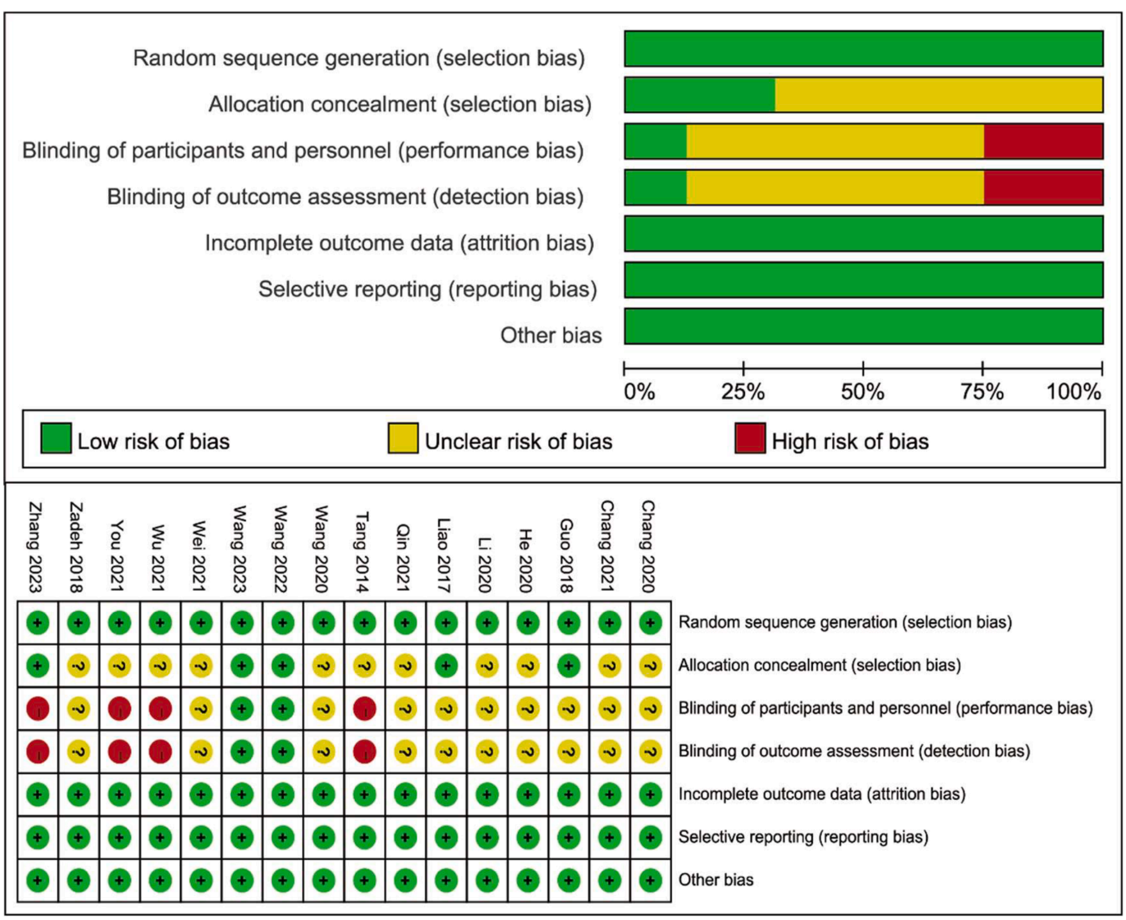

Fig. 2. Graph and summary of the risk of bias.

Table 2
Acupuncture points selected to improve sleep quality

Acupoint	Frequency (n [%])
PC6	7 (43.75%)
HT7	5 (31.25%)
LI4	4 (25.00%)
EX-HN3, SP6	3 (18.75%)
DU20, BL23, DU14, CO15, ST36	2 (12.50%)
CO10, CO12, BL62, KI6, EX-HN0, LU11, DU4, RN8, RN4, BL15, BL18, BL20	1 (6.25%)

Anmian (EX-HN0), Shaoshang (LU11), Mingmen (DU4), Shenque (RN8), Guanyuan (RN4), Xinshu (BL15), Ganshu (BL18), and Pishu (BL20).

3.4. Effect of TEAS on sleep quality

3.4.1. Pooled estimate of all studies

A meta-analysis was performed for change in PSQI score across all studies. In four studies, no explicit PSQI score data were reported [42, 47,50,54]. Therefore, twelve studies were included in the meta-analysis. Since each study collects PSQI at different time points, to reduce heterogeneity, only the most similar time points between the studies were selected for analysis. Because the follow-up time in Chang et al.' study [41] was not specified and could not be determined by reading the full article, it was also not assigned to any subgroup for analysis. The pooled estimation [40,43–46,48,49,51–53,55] showed that TEAS led to significantly greater improvement in PSQI scores than control group (MD -2.22; 95% CI [-3.29, -1.15]; $p<0.0001$) in the random-effects model. Specifically, the improvement in PSQI score was 2.22 points higher in the TEAS group. However, as the statistical heterogeneity was high ($I^2=92\%$; $p<0.00001$) across all studies (Fig. 3A), the results may not be sufficiently reliable.

A funnel plot (Fig. 4.) was drawn to assess the potential publication bias of the included studies. The funnel plots were asymmetrical, suggesting publication bias. To explore the source of heterogeneity, the studies were divided into two categories based on the cause of insomnia and subgroup analysis was then performed.

3.4.2. TEAS improves sleep quality in postoperative patients

Seven RCT studies [41–47] reported that TEAS improves postoperative sleep quality in patients. Of these, two studies [42,47] did not explicitly report PSQI score data. Thus, only five studies [41,43–46] are included in the meta-analysis. The results showed that TEAS effectively improved the postoperative sleep quality of patients, but with high heterogeneity (MD -0.95; 95% CI [-1.62, -0.27], $p=0.006$; $I^2=66\%$; Fig. 3B). The studies by Li et al. [43], Qin [44], Wang et al. [45], and Wang et al. [47] showed that TEAS, whether performed intraoperatively

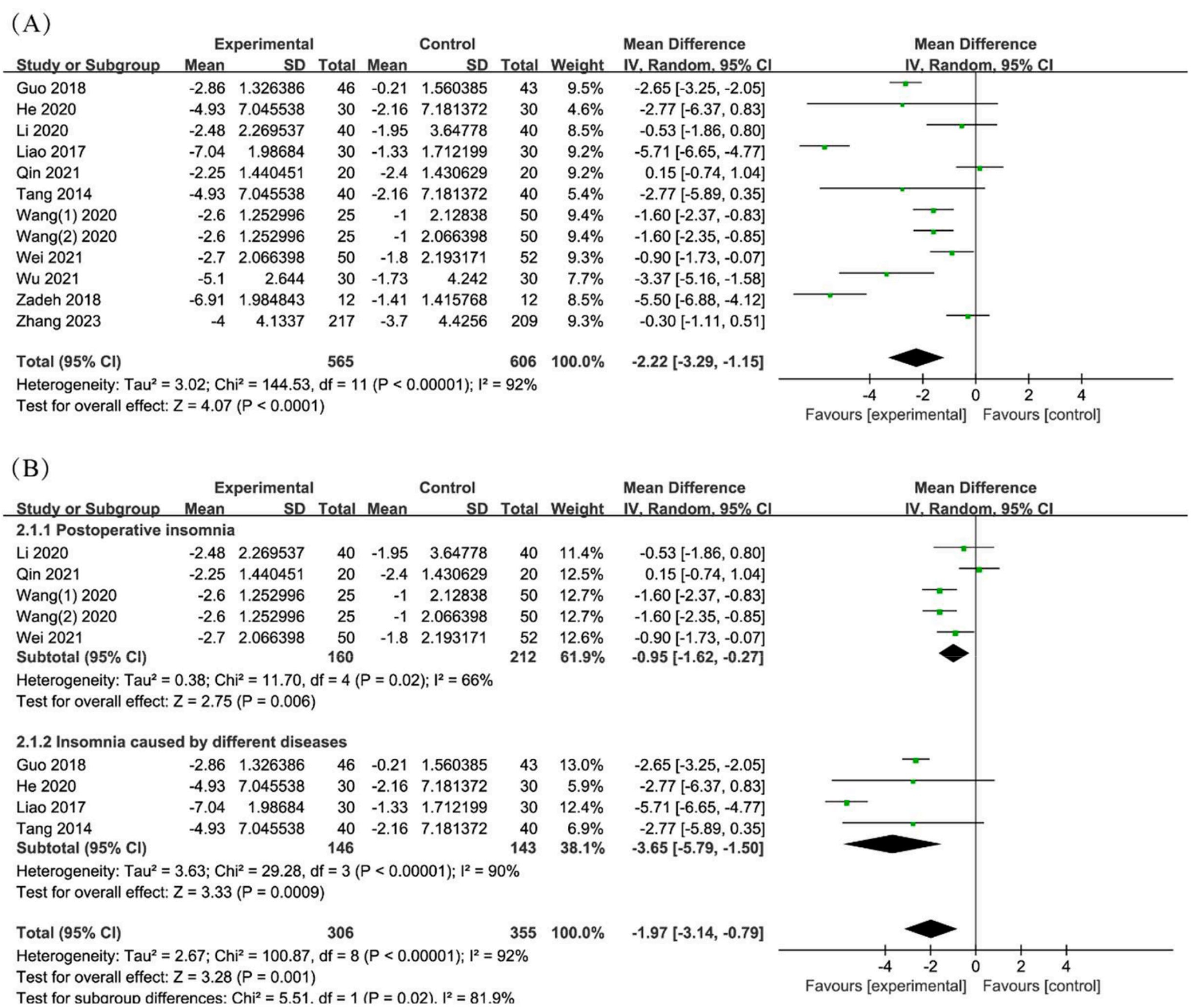

Fig. 3. Forest plots of TEAS/control group on PSQI score improvement.
A: Pooled meta-analysis. B: Subgroup analysis by causes of insomnia. Wang 2020: The stimulation methods of the two sham stimulation groups were non-electrical stimulation (1) and transcutaneous non-acupoint electrical stimulation (2).

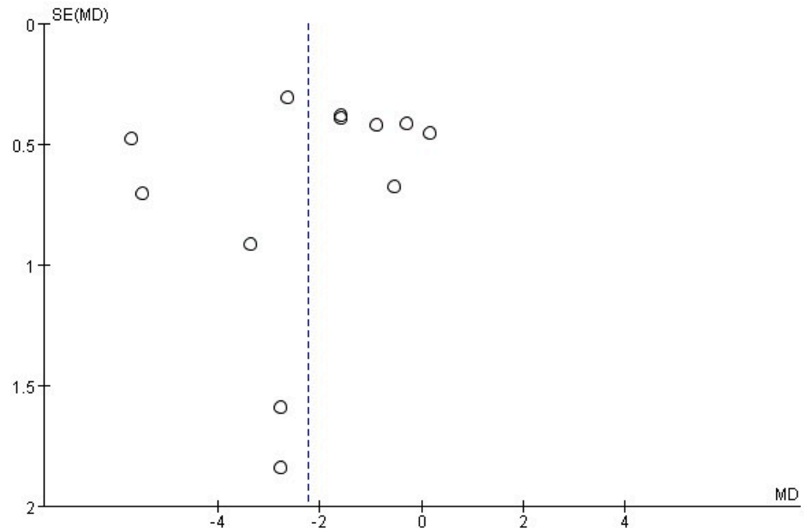

Fig. 4. Funnel plot of post-treatment PSQI score change compared to baseline of pooled meta-analysis.

only, intraoperatively and on days 1, 2, and 3 postoperatively, on the night before surgery, the night of the surgery, and on the first night after surgery, improved sleep disturbances more rapidly compared to sham in patients with surgically induced sleep disturbances. Qin's study [44] found that TEAS improved postoperative sleep quality and that the effect may relate to increased urinary melatonin levels and a reduction in the amount of propofol used during surgery. Wang et al.'s study [47] suggests that TEAS may improve postoperative sleep disturbance due to activation of the Nrf2 signal pathway. Chang's study [42] and Qin's study [44] both concluded that TEAS relieved postoperative pain and

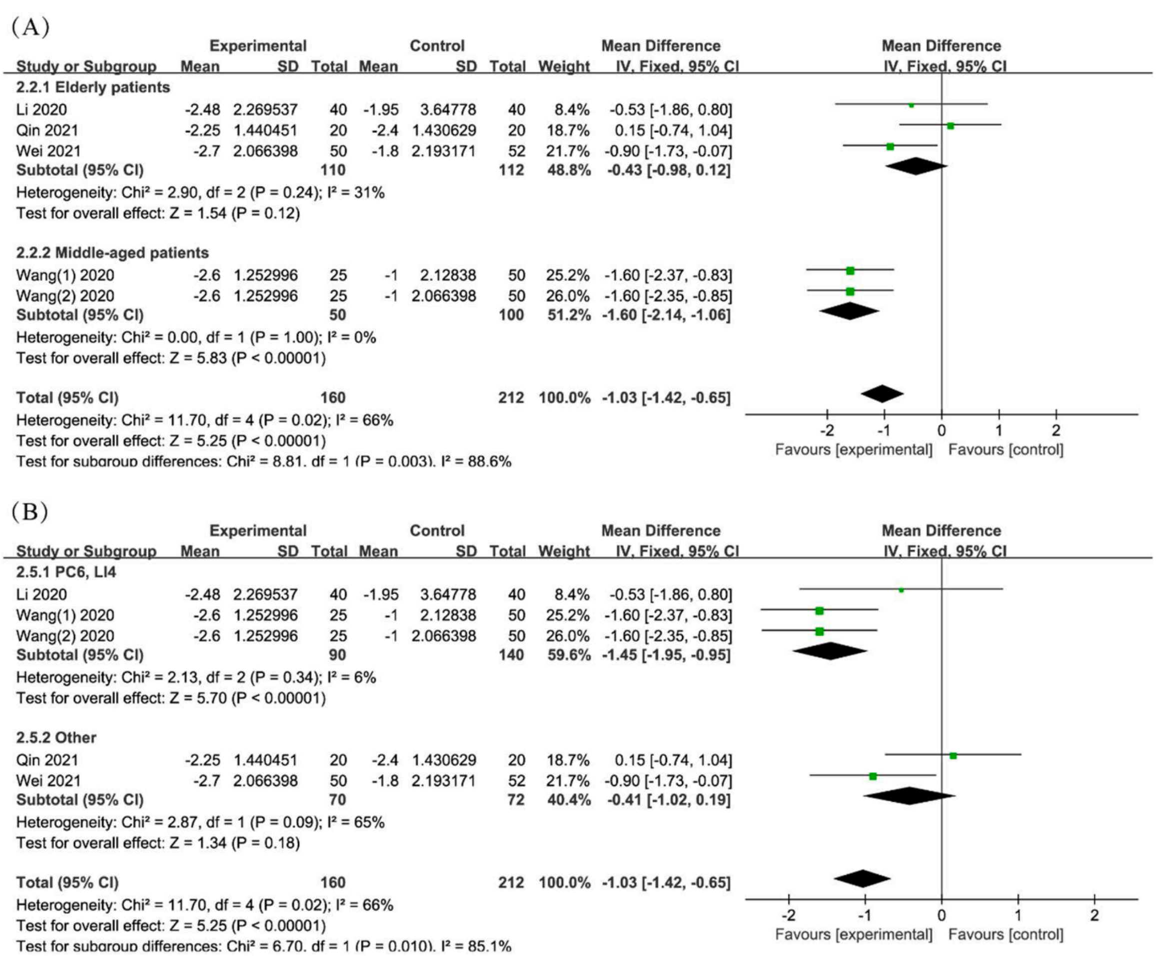

Fig. 5. Forest plot of postoperative patient subgroup analysis.
Subgroup analysis by age (A) and acupuncture points (B). Wang 2020: The stimulation methods of the two sham stimulation groups were non-electrical stimulation (1) and transcutaneous non-acupoint electrical stimulation (2).

improved postoperative sleep. Chang et al.'s study [41] used multimodal postoperative analgesia to exclude the impact of pain on sleep and proved that TEAS alone improved sleep quality. Another study by Wei et al. [46] showed that, in addition to improving sleep quality, TEAS could prolong the duration of deep sleep and improve sleep structure after surgery.

We observed that I^2=66% was close to 50%, and there were some differences in the characteristics of the included studies. Thus, to explore the reasons for the high heterogeneity, we performed subgroup analyses based on age and acupuncture points.

3.4.2.1. Subgroup analysis by age. A subgroup analysis was performed according to age (Fig. 5A). TEAS was effective for middle-aged patients (MD -1.60; 95% CI [-2.14, -1.06]; p<0.00001) with low heterogeneity (I^2=0%; p=1.00) and did not effectively improve postoperative insomnia in elderly patients (MD -0.43; 95% CI [-0.98, 0.12]; p=0.12) with low heterogeneity (I^2=31%; p=0.24). There was a difference between the two age groups (p<0.05), suggesting that TEAS could be more suitable for improving postoperative sleep quality in middle-aged patients. In addition, the amount of data in the middle-aged group was insufficient, although the degree of heterogeneity was low, its efficacy may be unstable and further research was required. By comparing the three studies included in the elderly group, it was found that there were also differences in the type of surgery, time point of treatment, and acupuncture points. Therefore, subsequent studies of the same type could be conducted to explore this further.

3.4.2.2. Subgroup analysis by acupuncture points. Subgroup analysis was performed according to the stimulated acupuncture points (Fig. 5B). Due to the limited number of articles, studies were divided into two groups based on acupuncture points: (i) PC6, LI4 and (ii) other acupuncture points. The efficacy of TEAS was significant for both PC6, LI4 (MD -1.45; 95% CI [-1.95, -0.95], p<0.00001; I^2=6%) and other acupuncture points (MD -0.41; 95% CI [-1.02, 0.19], p=0.18; I^2=65%). The MD for PC6, LI4 group was better, indicating that TEAS stimulation of PC6 and LI4 acupoints has a better effect on sleep quality in postoperative patients. Although the difference was statistically significant (p=0.01), two pieces of data were derived from the same study, and more studies of the same type are needed to provide stronger support.

3.4.3. TEAS improves sleep quality in patients with depression

Only two RCTs [48,49] compared the efficacy of TEAS with escitalopram. Due to the lack of data, a meta-analysis was not conducted. Among the two RCTs, one study [48] recruited 60 patients with depression and treated them for 4 weeks. The results showed a significant difference in PSQI score between the test group (-5.10±2.64) and control group (-1.73±4.24) before and after treatment (p=0.001). These findings suggest that TEAS is more effective than escitalopram oxalate for improving subjective sleep quality among patients with depression. The other study [49] recruited 470 patients with mild to moderate depression for 8 weeks of treatment. PSQI scores at weeks 4, 8, and 21 all indicated significant improvement in sleep quality, and there was no difference in the degree of improvement between the two groups at any post-treatment measurement point (p>0.05). These results suggest that the efficacy of TEAS and escitalopram for improving sleep quality among patients with depression is comparable.

3.4.4. TEAS improves sleep quality in patients with shift insomnia

Only one RCT [40] investigated the efficacy of TEAS for improving insomnia in shift workers. As a result, meta-analysis could not be performed. The study included a total of 24 nurses with sleep disorders due to shift work. After the intervention, the total PSQI score in the test group (p<0.001) and control group (p=0.016) were both significantly reduced. However, there was a statistically significant group difference after the intervention (p<0.001) indicating that TEAS can effectively improve sleep quality among shift nurses with insomnia.

3.4.5. TEAS improves sleep quality in patients with insomnia caused by other diseases

Six RCTs [50–55] reported that TEAS can improve insomnia symptoms caused by different diseases. You's study [50] examined the efficacy of TEAS for the treatment of methamphetamine use disorder with protracted insomnia. Liao [51] studied the clinical efficacy of TEAS for the treatment of late-onset insomnia in methamphetamine-dependent patients. Guo et al. [52] used TEAS to treat chronic fatigue syndrome sleep disorders. He et al. [53] evaluated the efficacy of TEAS in patients with glomus hysteria. Wang et al. [54] evaluated whether TEAS improved sleep quality while improving cognitive function in patients with mild cognitive impairment. Tang et al. [55] examined the efficacy of TEAS for treating insomnia after stroke. Of these six studies, two [50, 54] did not explicitly report PSQI score data. Thus, four studies [51–53, 55] are included in the meta-analysis. For insomnia caused by other diseases, meta-analysis showed that the TEAS intervention was effective, but that the results may be not sufficiently reliable (MD -3.65; 95% CI [-5.79, -1.50], I^2=90%, Fig 3B). Two RCTs compared the efficacy of TEAS with oral eszopiclone [50] and estazolam [55] and found that TEAS was equally effective for improving methamphetamine use disorder with protracted insomnia and post-stroke insomnia. Four RCTs showed that TEAS is effective, while sham stimulation is not, for insomnia in patients with delayed methamphetamine dependence [51], chronic fatigue [52], glomus hysteria [53], and mild cognitive impairment [54]. Liao' s study [51] found that TEAS may improve insomnia symptoms by increasing serum 5-HT levels. He et al.'s study [53] found that transcutaneous electrical stimulation of acupoints and non-acupoints improved insomnia. However, the effect of electrical stimulation of acupoints was significantly better (p<0.05).

3.5. Adverse events

Adverse events were reported in 4 of the 16 studies, and no significant adverse events were described. Two studies [48,49] reported that the adverse events were mild, transient, and resolved spontaneously. The adverse events included headache, agitation, facial twitching, and hot flashes. Some participants reported short auricular pain caused by the electrode clip. In one study [54], a patient with a history of tympanic membrane perforation developed a mild toothache, sore throat, and tinnitus after 13 weeks of intervention. The patient returned to normal 1 week after stopping the intervention. Another study [46] reported that two patients had difficulty tolerating the shock-like sensation of TEAS. Notably, two studies [43,45] reported that TEAS reduced the incidence of postoperative adverse effects in patients.

4. Discussion

4.1. Main findings

This review and meta-analysis quantitatively demonstrated the effectiveness of TEAS for improving postoperative insomnia among middle-aged patients. Subsequent subgroup analyses found that the evidence for the efficacy of TEAS stimulating the PC6 and LI4 acupoints simultaneously was more reliable. Although positive effects were also reported for patients with delayed methamphetamine use disorder, delayed methamphetamine dependence, chronic fatigue, glomerular hysteria, mild cognitive impairment, and post-stroke insomnia, the reliability of the results was not high and further research is needed. The findings also indicated that TEAS may be effective for depressive insomnia and shift work insomnia. The included studies suggested that the underlying mechanisms of TEAS's positive effects on sleep quality may relate to increased intraoperative urinary melatonin levels or decreased propofol dosage during surgery [44]. In delayed insomnia in methamphetamine-dependent patients, TEAS may improve sleep quality by increasing serum serotonin levels [51]. The included studies showed that TEAS has few adverse effects, a high safety profile, and high acceptability. However, there are gaps in knowledge of the efficacy and mechanism of TEAS for improving sleep quality and insomnia caused by other psychological, physiological, or pathological factors in children and adolescents, which deserve further exploration. Further research on this topic is thus warranted.

4.2. Comparison with previous studies

The efficacy of acupuncture for insomnia was previously systematically reviewed by Cheuk et al. [56], who evaluated TEAS as a variant of acupuncture. However, as only one RCT trial had been performed at that time, only a quantitative systematic review was performed due to the number of studies that could not be included in a meta-analysis. The authors concluded that, although individual studies [57] suggested that TEAS might improve sleep quality scores, there was insufficient evidence that TEAS is an effective therapy. To the best of our knowledge, our study is the first meta-analysis to evaluate the effects of TEAS on sleep quality.

4.3. Implications for clinical practice

Clinicians may make evidence-based decisions about the use of TEAS to improve sleep quality based on the latest studies with a low risk of bias [47,49,54]. TEAS may be considered for improving sleep disturbances due to chronic fatigue or to improve insomnia symptoms of methamphetamine dependence in the protracted period. Based on the results of this meta-analysis, intraoperative and postoperative TEAS were effective for alleviating sleep quality in perioperative period, especially among middle-aged patients. The results of subgroup analysis suggested that PC6 and LI4 were effective acupoints for improving sleep quality among postoperative patients.

4.4. Implications for future research

This systematic review identified 16 RCTs assessing TEAS interventions to improve sleep quality. Given the high prevalence and burden of reduced sleep quality, more high-quality studies are needed to determine the short- and long-term effectiveness of TEAS. In addition to the effects of TEAS, researchers should consider the specific implementation of TEAS, including the duration of treatment, the intensity and frequency of current stimulation, and the selection of acupuncture points. In future studies, the optimal delivery method and potential therapeutic mechanism could be explored. In the studies reviewed here, sham stimulation consisted of placing energized electrodes in areas close to but not at acupuncture points (non-acupuncture points) and electrodes placed at the same acupuncture points without power. While the specific effects produced by acupuncture points may not occur at non-acupuncture point areas, these sites may still be physiologically active and produce therapeutic effects [53]. In other words, as electrical stimulation of non-acupuncture points may not be a completely physiologically inert treatment, researchers may need a larger sample size to detect significant differences. This may also apply for sham stimulation, as the placebo and Hawthorn effects can mask results [58]. A few studies have explored the potential mechanism of how TEAS improves sleep quality. Generally, researchers analyze only one or two relevant objective indicators in their study. Due to the small number of relevant studies, it is unclear how TEAS improves sleep quality. Future studies should assess more objective sleep-related indicators and analyze the treatment mechanisms of different TEAS methods for different types of insomnia or sleep disorders. As TCM is the medical system in China and has specific treatment methods, most relevant research is carried out and published locally. If possible, researchers should conduct RCTs in accordance with CONSORT guidelines [59].

4.5. Limitations

This review is subject to some limitations. Firstly, the search was limited to publications in English and Chinese databases. As a result, relevant studies published in other languages may be missed. Secondly, critically evaluating articles requires scientific judgment, which may vary from reviewer to reviewer. This source of bias can be limited by training reviewers and using standardized critical appraisal tools. Third, there were differences in the causes of insomnia, study duration, control group settings, and acupoints used in the included studies, leading to a high degree of heterogeneity. Fourth, the small number of studies in each subgroup of the subgroup analyses reduced the reliability of the findings. Fifth, the generalization of our findings is limited to insomnia due to postoperative state, depression, shift work, and different diseases and the types of TEAS identified in our review. Lastly, qualitative studies exploring the lived experiences of patients with improved sleep quality due to TEAS were not included.

5. Conclusion

This meta-analysis supports that TEAS has the potential to improve postoperative sleep quality in middle-aged patients and was thus worthy of clinical promotion. Using TEAS to simultaneously stimulate the PC6 and LI4 acupoints is an effective treatment method to improve postoperative sleep quality. For insomnia caused by other factors, due to the small sample sizes and high heterogeneity between studies, more high-quality, large-scale, multicenter RCTs are needed to provide more reliable evidence for the effectiveness of TEAS in improving sleep quality.

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CRediT authorship contribution statement

Jia-rui Zhang: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Yi Ruan:** Writing – review & editing, Investigation, Funding acquisition, Formal analysis. **Xin Wang:** Writing – review & editing, Formal analysis. **Yan-li You:** Writing – review & editing, Formal analysis. **Zi-fei Yin:** Writing – review & editing, Methodology, Conceptualization. **Wei Gu:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data and retrieval methods have been provided in the article and appendix.

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Supplementary materials

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