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Obstructive sleep apnea increases the risk of cardiac events after percutaneous coronary intervention: a meta-analysis of prospective cohort studies

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Abstract
Purpose Recent studies have shown an association between obstructive sleep apnea (OSA) and coronary artery disease; however, the association between OSA and cardiac outcomes in patients after percutaneous coronary intervention (PCI) remains undetermined.
Methods PubMed, EMBASE, and CENTRAL were searched from inception to July 2016 for cohort studies that followed up with patients after PCI, and evaluated their overnight sleep patterns within 1 month for major adverse cardiac events (MACEs) as primary outcomes including cardiac death, non-fatal myocardial infarction (MI), and coronary revascularization and secondary outcomes including re-admission for heart failure and stroke. Outcomes data were pooled using fixed-effect meta-analysis, and heterogeneity was assessed with the I^2 statistics. The methodological quality of the studies was assessed using the Newcastle-Ottawa Scale checklist, and publication bias was evaluated by a visual investigation of funnel plots.
Results We identified seven pertinent studies including 2465 patients from 178 related articles. OSA was associated with MACEs (odds ratio [OR], 1.52, 95% confidence interval [CI], 1.20–1.93, I^2 = 29%), which included cardiac death (OR 2.05, 95% CI, 1.15–3.65, I^2 = 0%), non-fatal MI (OR 1.59, 95% CI, 1.14–2.23, I^2 = 15%), and coronary revascularization (OR 1.69, 95% CI, 1.28–2.23, I^2 = 0%). However, OSA was not associated with re-admission for heart failure (OR 1.71, 95% CI, 0.99–2.96, I^2 = 0%) and/or stroke (OR 1.68, 95% CI, 0.91–3.11, I^2 = 0%) according to the pooled results.
Conclusions In patients after PCI, OSA appears to increase the risk of cardiac death, non-fatal MI, and coronary revascularization.

Keywords Obstructive sleep apnea · Percutaneous coronary intervention · Cardiac outcomes · Cardiac death · Meta-analysis · Systematic review

Introduction

Obstructive sleep apnea (OSA), a common sleep-disordered breathing condition, is a risk factor for cardiac events including heart failure, atrial fibrillation, stroke, and coronary artery disease [1–4]. Epidemiological studies have shown that OSA is present in about 50% of patients with percutaneous coronary intervention (PCI); however, observational cohort studies focusing on the association between cardiac outcomes and OSA have documented controversial conclusions [5, 6]. For example, a study by Meng et al. showed no statistical difference in major adverse cardiac events (MACEs) between PCI patients with and without

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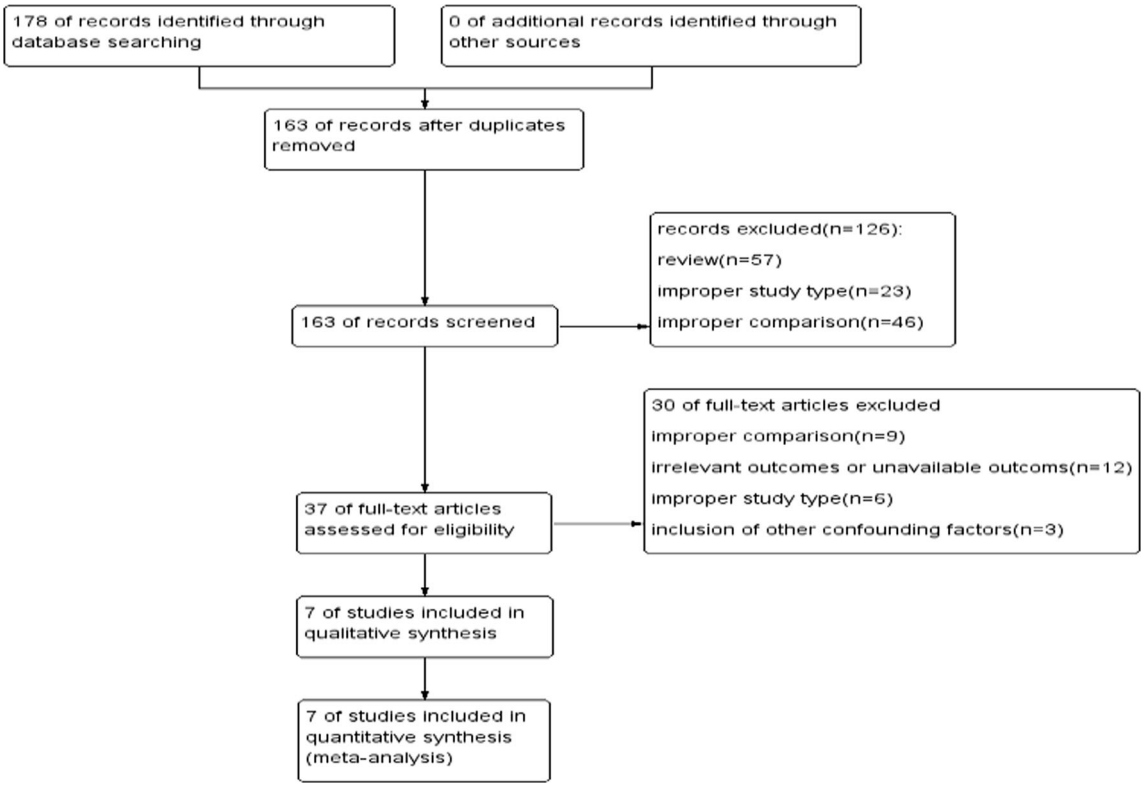

Fig. 1 Literature search process and study selection

OSA [7]. In contrast, a study by Chi et al. revealed an increased risk of MACEs in PCI patients with OSA compared to those without OSA, while another study by Jun also showed a significant difference between PCI patients with OSA and coronary artery disease patients without OSA, with respect to MACEs [5, 8]. Treatments like antiplatelet, statin, and/or β-blocker have been recommended as second-choice preventative measures to be used in PCI patients, while the impact of OSA on PCI patients is often ignored. The present meta-analysis evaluated whether OSA is associated with the MACES of PCI patients.

Methods

The meta-analysis was performed according to the guidelines of the Meta-analysis of Observational Studies in Epidemiology (MOOSE) group (Appendix 1) [9].

Table 1 Basic characteristics of the patients

Study	Study design	Participants	Age	Men (%)	Different exposure
Hiroshi 2014	Prospective cohort study	272	Range (56–78)	75%	Moderate-to-severe OSA group (AHI ≥15 events/h)/the reference group (AHI <15 events/h)
Dai 2006	Prospective cohort study	89	66 ± 11	77.50%	OSA group (AHI ≥10 events/h)/no-OSA group (AHI <10 events/h)
Meng 2014	Prospective cohort study	123	66.7 ± 10.9	69.10%	OSA group (AHI ≥5 events/h)/ no-OSA group (AHI <5 events/h)
Jun 2016	Prospective cohort study	340	64.69 ± 10.38	73.20%	OSA group (AHI ≥15 events/h)/non-OSA group (AHI <15 events/h)
Chi 2016	Prospective cohort study	1311	58.2 ± 10.3	85.20%	OSA group (AHI ≥15 events/h)/no-OSA group (AHI <15 events/h)
Germaine 2014	Prospective cohort study	68	54.2 ± 8.8	86.80%	OSA group (AHI ≥15 events/h)/non-OSA group (AHI <15 events/h)
Wu 2015	Prospective cohort study	262	55.64 ± 11.43	84.73%	Moderate-severe OSA group (AHI ≥15 events/h)/mild OSA group (5< AHI <15 events/h)

OSA obstructive sleep apnea, *AHI* apnea-hypopnea index

Table 2 Included patients, outcomes, results, and risk of bias

Study	Patient selection	Key exclusion criteria	Risk factor adjustment	Clinical outcomes	Mean follow-up time
Hiroshi 2014	Acute MI and undergoing primary PCI	Disrupted examination or missing sleep parameters; the time of follow-up less than 1 year	Hypercholesterolemia, hypertension, diabetes, current smoking, BMI of ≥25 kg/m^2, age ≥75 years, and male gender	1. MACEs (cardiac death, ACS recurrence, and re-admission for heart failure) 2. Cardiac death 3. Recurrent acute MI 4. Unstable angina 5. ACS recurrence 6. Re-admission for heart failure 7. Unplanned PCI	4.04 years
Dai 2006	Undergoing urgent or elective PCI for ACS	Cardiogenic shock or New York Heart Association functional class III/IV heart failure or sleep apnea of the central type	Hypertension, hypercholesterolemia, diabetes mellitus, smoking, age, BMI, ejection fraction, high-sensitivity C-reactive protein, Epworth Sleepiness Scale	1. MACEs (cardiac death, re-infarction, and target vessel revascularization) 2. Cardiac death 3. Target vessel revascularization	227 days
Meng 2014	Undergoing urgent or elective PCI for ACS	Previous AMI, previous coronary stenting or coronary artery bypass graft (CABG), cardiogenic shock, New York Heart Association function class III/IV heart failure, or sleep apnea of the central type	Hypertension, diabetes mellitus, hypercholesterolemia, BMI, age	1. MACEs (cardiac death, target vessel revascularization, re-admission for heart failure, stroke) 2. Cardiac death 3. Re-admission heart failure 4. Target vessel revascularization 5. Stroke	1 year
Jun 2016	Patients who were treated with DES implantation	Treatments for OSA; cardiogenic shock with SBP <90 mmHg; clinical heart failure requiring oxygen supplement; perceived high risk of malignant ventricular arrhythmia; pregnancy; history of malignancy	Age, male, BMI, hypertension, current smoker, diabetes mellitus, ejection fraction, hsC-reactive protein, total implanted stents, multivessel disease	1. MACEs (cardiac death, MI, target vessel revascularization) 2. Cardiac death 3. MI 4. Target vessel revascularization	2 years
Chi 2016	Undergoing a successful PCI in at least one epicardial coronary artery	OSA on continuous positive airway pressure therapy, cardiogenic shock on mechanical ventilation and/or intra-aortic balloon pump, perceived high risk for malignant arrhythmia receiving sedation or a muscle relaxant, ongoing heart failure	Age, sex, ethnicity, BMI, hypertension, and diabetes mellitus	1. MACCEs (cardiovascular mortality, non-fatal MI, and unplanned revascularization) 2. Non-fatal stroke 3. All-cause mortality 4. Target vessel revascularization 5. Stent thrombosis 6. Re-admission for heart failure	1.9 years
Germaine 2014	Presenting with ACS and treated with PCI	OSA treated with continuous positive airway pressure therapy or previous intervention treatment of the target vessel, cardiogenic shock, chronic renal failure on dialysis, or atrial fibrillation	Age, gender, different ACS presentations, hypertension, smoking, and BMI	1. MACCEs (non-fatal MI, unplanned revascularizations, strokes, re-admission for congestive heart failure) 2. Non-fatal MI 3. Unplanned revascularizations 4. Strokes 5. Re-admission for congestive heart failure	24 months
Wu 2015		OSA treated with continuous positive airway pressure therapy		1. MACEs (death, non-fatal MI, repeat	4.8 years

Table 2 (continued)

Study	Patient selection	Key exclusion criteria	Risk factor adjustment	Clinical outcomes	Mean follow-up time
	Undergoing urgent or elective PCI		Age, sex, BMI, clinical presentation, smoking, hypertension, diabetes, dyslipidemia, history disease	revascularization, and stent thrombosis) 2. MACCEs (MACE or stroke) 3. Cardiac death 4. Non-fatal MI 5. Stroke	

MI myocardial infarction, *PCI* percutaneous coronary intervention, *OSA* obstructive sleep apnea, *BMI* body mass index, *ACS* acute coronary syndrome, *MACEs* major adverse cardiac events, *MACCEs* major adverse cardiac and cerebrovascular events, *SBP* systolic blood pressure

Data source and search strategies

Two reviewers (i.e., Hua Qu and Ming Guo) searched PubMed, EMBASE, and CENTRAL with no language restrictions from inception to July 2016 to identify all existing literature. Mesh terms and free-text terms were used in each database with the following relevant keywords: ("apneas, obstructive sleep" OR "obstructive sleep apneas" OR "sleep apneas, obstructive" OR "obstructive sleep apnea syndrome" OR "obstructive sleep apnea" OR "OSAHS" OR "syndrome, sleep apnea, obstructive" OR "sleep apnea syndrome, obstructive" OR "apnea, obstructive sleep" OR "sleep apnea hypopnea syndrome" OR "syndrome, obstructive sleep apnea" OR "upper airway resistance sleep apnea syndrome" OR "syndrome, upper airway resistance, sleep apnea" OR "obesity hypoventilation syndrome") AND ("percutaneous coronary intervention" OR "coronary intervention, percutaneous" OR "coronary interventions, percutaneous" OR "intervention, percutaneous coronary" OR "interventions, percutaneous coronary" OR "percutaneous coronary interventions" OR "percutaneous coronary revascularization" OR "coronary revascularization, percutaneous" OR "coronary revascularizations, percutaneous" OR "percutaneous coronary revascularizations" OR "revascularization, percutaneous coronary" OR "revascularizations, percutaneous coronary" OR "angioplasty, balloon, coronary" OR "atherectomy, coronary") AND ("follow-up studies" OR "prospective studies" OR "cohort studies" OR "longitudinal studies" OR "observational studies"). A manual search was also performed to identify relevant references from the selected articles and published reviews.

The studies were considered to be eligible if they met the following inclusion criteria: (1) cohort study; (2) contained overnight sleep studies scheduled in the patients within 1 month after PCI; (3) contained information on patients with OSA (varying degrees of OSA severity) and without OSA; and (4) included MACEs (including cardiac death, no-fatal MI, coronary revascularization) as primary outcomes, and re-admission for heart failure and stroke as secondary outcomes.

Data extraction and assessment of study quality

Two reviewers (i.e., Hua Qu and Ming Guo) extracted data independently, and any disagreement was resolved by consulting with the third investigator (i.e., Da-zhuo Shi). Attempt was made to contact authors who published their studies only with abstracts, but, failing to obtain original data, these studies were excluded from the present study. Data in detail was extracted from each individual study that ultimately was included in the present study, including the following: (1) the first authors' name and publication year; (2) study design; (3) participants' age; (4) percentage of males; (5) patient selection; (6) different exposure; (7) key exclusion criteria; (8) risk factor adjustment; (9) clinical outcomes; and (10) mean follow-up time. Because of the inconsistent definitions of MACEs in the included

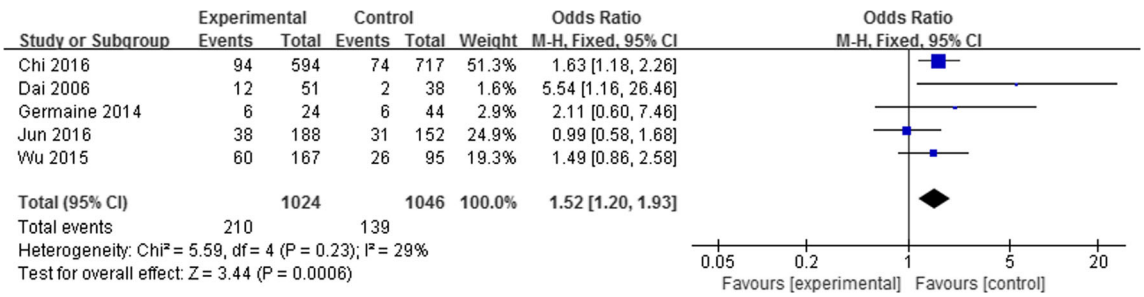

Fig. 2 Fixed-effect analysis of MACEs associated with OSA

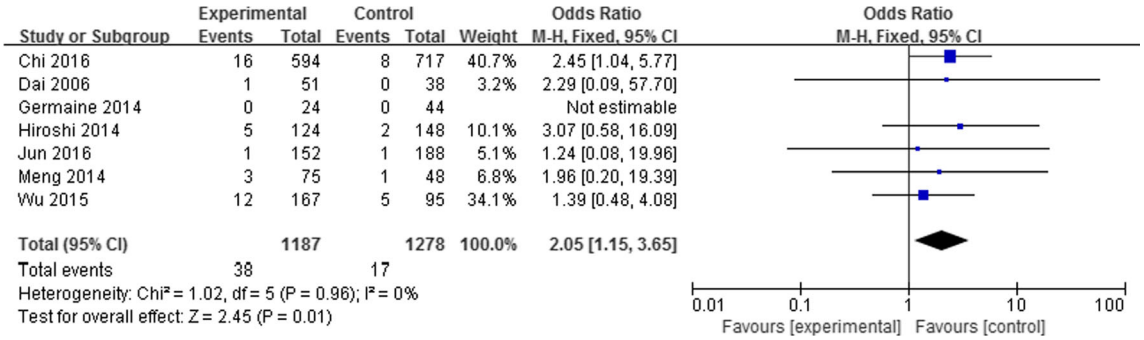

Fig. 3 Fixed-effect analysis of cardiac death associated with OSA

studies, MACEs were prespecified in the present meta-analysis as cardiac death, no-fatal MI, and/or coronary revascularization. The methodological quality of studies was assessed using the NOS checklist, with the highest score (i.e., the score meaning better quality) being 9 (Appendix 2) [10].

Statistical analysis

In this meta-analysis, dichotomous data was used to analyze the odds ratio (OR) with the effects size as indicated by the 95% confidence interval (CI), because adjusted OR, relative risk (RR), or hazard ratio (HR) was unavailable in certain instances and/or inconsistent. Heterogeneity among studies was evaluated using the chi-square test based on Cochran's Q test and I^2 statistic at the $P < 0.10$ level of significance, and quantification of heterogeneity was performed using the I^2 metric, which describes the percentage of total variation in point estimated to be due to heterogeneity rather than chance [11, 12]. Low, moderate, and high degrees of heterogeneity were categorized by I^2 values of 25, 50, and 75%, respectively [12, 13]. When P for the heterogeneity was <0.1 and $I^2 < 30\%$, the inter-study heterogeneity was to be considered statistically significant. Because of the low heterogeneity of our outcomes, however, sensitivity analysis was not performed, and instead, fixed-effect models were applied for analysis [12]. The publication bias was evaluated by a visual investigation of funnel plots for potential asymmetry (Appendix 3) [14]. Statistical analyses were performed using the Cochrane Collaboration (RevMan 5.3, Copenhagen, Denmark). There is no registered protocol for the present meta-analysis.

Results

Description of included studies

One hundred seventy-eight studies (29 from PubMed, 143 from EMBASE, and 6 from CENTRAL) were identified, and 163 articles remained after the exclusion of duplicate articles. Following the screening of the titles and abstracts, a total of 143 articles were excluded due to being of a traditional review format and/or improper study type, or having improper comparisons contained within. Overall, we evaluated the full text of 37 publications. Of these, 30 studies were excluded because of improper comparison and or/due to being irrelevant to the outcomes or having unavailable outcomes. Other confounding factors, such as discussing central sleep apnea or coronary artery bypass surgery, also made for exclusion. In the end, seven cohort studies were entered into our meta-analysis [5–8, 15–17]. The specific process of study selection is presented in Fig. 1.

Tables 1 and 2 show the characteristics of seven cohort studies published in English from 2006 to 2016, with a total of 2465 patients included in this meta-analysis. The sample of the study ranged from 68 to 1311, and the mean follow-up time was from 227 days to 4.8 years. Overall, seven studies investigated the

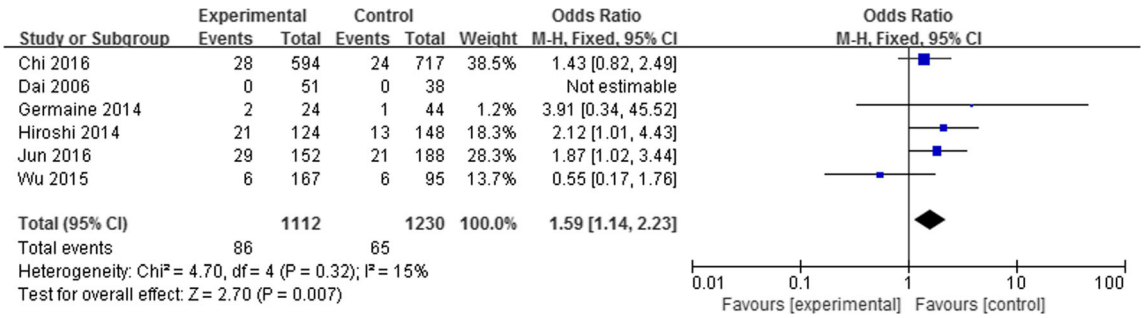

Fig. 4 Fixed effects analysis of MI associated with OSA

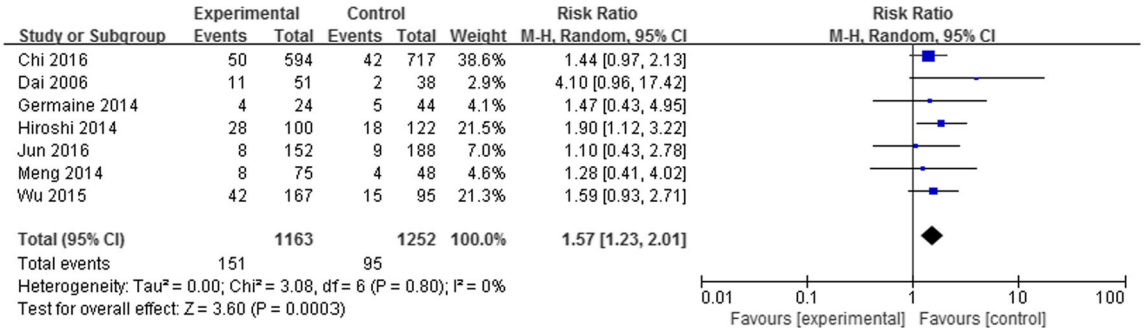

Fig. 5 Fixed-effect analysis of coronary revascularization associated with OSA

cardiac death and coronary revascularization, six studies assessed the risk of no-fatal MI, and four studies evaluated stroke and/or re-admission for heart failure [5–8, 15–17].

The mean Newcastle-Ottawa Scale (NOS) score of study quality for these seven studies was 7.5. Appendix 1 shows the quality assessment of the study according to the NOS criteria. Exploration regarding the funnel plot of OSA and cardiac death, no-fatal MI, and coronary revascularization showed no asymmetry, which suggested no obvious evidence of publication bias (Appendix 3).

Primary outcomes

Five studies (2070 patients) evaluated the association between OSA and MACEs of PCI patients. There was no significant heterogeneity ($P = 0.23$, $I^2 = 29\%$) across these studies; thus, a fixed-effect model was used. The pooled estimates showed a significant association between MACEs and OSA (OR 1.52, 95% confidence interval [CI], 1.20–1.93) (Fig. 2).

Seven studies (2465 patients) reported a significant association between OSA and cardiac death (OR 2.05, 95% CI, 1.15–3.65), with no substantial heterogeneity ($P = 0.96$, $I^2 = 0\%$); six studies (2342 patients) with low heterogeneity ($P = 0.32$, $I^2 = 15\%$) documented an association between OSA and non-fatal MI (OR 1.59, 95% CI, 1.14–2.23); and seven studies (2415 patients) with no observed heterogeneity ($P = 0.70$, $I^2 = 0\%$) also showed an association between coronary revascularization and OSA (OR 1.69, 95% CI, 1.28–2.23) (Figs. 3, 4, and 5).

Secondary outcome

Four studies with a total of 1764 patients evaluated the association between OSA and stroke, demonstrating that OSA was not associated with stroke (OR 1.68, 95% CI, 0.91–3.11); four studies with a total of 1774 patients evaluated the association between OSA and re-admission for heart failure, showing that OSA was also not associated with re-admission for heart failure (OR 1.71, 95% CI, 0.99–2.96) (Figs. 6 and 7).

Discussion

To our knowledge, this is the first meta-analysis to evaluate the association between OSA and cardiac outcomes in PCI patients by polling the cohort studies. In this study, we aimed to identify whether OSA has an adverse effect on the incidence increase of MACEs, stroke, and re-admission for heart failure in PCI patients. The pooled analysis results revealed that OSA increased the risk of MACEs by 1.52 times, and among them specifically, cardiac death by 2.05 times, coronary revascularization by 1.69 times, and non-fatal MI by 1.59 times, when compared with no-OSA patients. In contrary, no significant differences were tested in the incidence of stroke and re-admission for heart failure between the two groups.

According to epidemiological studies, about 50% of PCI patients also exhibit OSA [5, 6]. Several studies proved that OSA was associated with early signs of

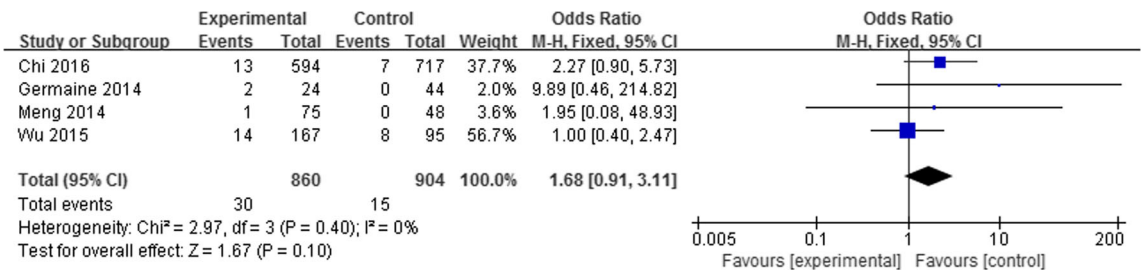

Fig. 6 Fixed-effect analysis of stroke associated with OSA

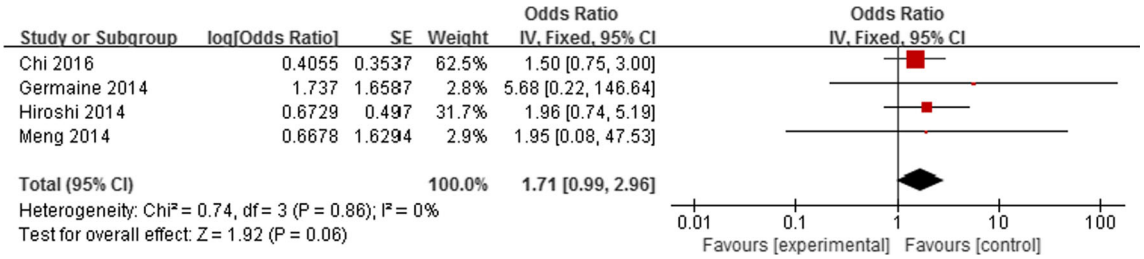

Fig. 7 Fixed-effect analysis of re-admission for heart failure associated with OSA

atherosclerosis and coronary plaque burden in the individuals without overt cardiovascular disease [18–20]. Two studies showed that OSA patients had a greater atheroma burden than non-OSA patients, as evidenced by coronary angiography and intravascular ultrasonography for evaluating symptomatic coronary artery disease [21, 22]. Episodes of obstructive apnea have been found to induce intermittent hypoxemia, CO_2 retention, and/or oxygen desaturation, as well as altered autonomic and hemodynamic responses, thus leading to surge in blood pressure due to sympathetic activation [23–27]. Endothelial dysfunction, increased inflammatory mediators, oxidative stress, and insulin resistance induced by OSA have also contributed to the increased risk in cardiac outcomes of patients [28–30].

In the present meta-analysis, no significant differences were found in re-admission for heart failure and stroke between OSA and non-OSA patients, which may be due to the relatively limited sample size and/or confounding factors such as older age or the use of different medications.

Study limitations

Several limitations in our meta-analysis should be noted. First, the total number of studies and thus the number of patients included in this study were limited. Second, the definition of MACEs was inconsistent in the included studies, which inevitably offered some bias and confounding factors; however, we predefined MACEs as cardiac death, non-fatal MI, and/or coronary revascularization according to the criterion included in the "the Sleep and Stent Study"; all of the data for this study was extracted based on the definition [5]. Third, in our meta-analysis, the criteria of OSA is inconsistent across individual studies, with five of the studies defining apnea hypopnea index (AHI) ≥15 events/h as OSA, one study defining OSA by AHI ≥5 events/h, and one study defining OSA by AHI ≥10 events/h; however, the pooled analyses in seven studies demonstrated that the association between OSA and cardiac outcomes is consistent regardless of any differences in the definition of OSA, suggesting that OSA is closely associated with increasing risk of MACEs.

Conclusions

In conclusion, OSA appears to increase the risk of MACEs including cardiac death, non-fatal MI, and coronary revascularization in PCI patients.

Author contributions Da-zhuo Shi designed the review and provided methodological perspectives; Hua Qu, Ming Guo, and Ying Zhang developed the search strategy and performed the literature search, study selection, data extraction, and data analyses. Hua Qu and Ming Guo contributed equally to this work and are co-first authors.

Compliance with ethical standards

Funding This work was supported by the National Natural Science Foundation of China (no. 81030063).

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Ethical approval was not necessary for this meta-analysis, as only identified pooled data from previously approved individual studies was used.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Comment

The question of whether or not OSA increases the risk of adverse outcome after PCI is one which has been addressed by a large number of studies. In this meta-analysis the authors show increased adverse events after PCI in those with OSA. Translating this into clinical practice is clearly of interest and with that in mind it is interesting to compare and contrast the approach of Cardiologists to defining procedural success in PCI in both stable and unstable coronary disease with the limited diagnostic and therapeutic success in sleep apnea. Simplified diagnostic methods are being incorporated into clinical pathways in OSA assessment but the greatest weakness remains adherence and efficacy monitoring which will be needed to change practice amongst Cardiologists used to more rigorous approaches to diagnosis and treatment.

Ian Wilcox
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