The association between oral hygiene and periodontitis: a systematic review and meta-analysis

Attawood Lertpimonchai1,2, Sasivimol Rattanasiri1, Sakda Arj-Ong Vallibhakara1, John Attia3,4 and Ammarin Thakkinstian1

1Section for Clinical Epidemiology and Biostatistics, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand; 2Department of Periodontology, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand; 3School of Medicine and Public Health, Centre for Clinical Epidemiology and Biostatistics, University of Newcastle, Newcastle, Newcastle, NSW, Australia; 4Hunter Medical Research Institute, Newcastle, Newcastle, NSW, Australia.

Objective: Dental plaque accumulation and inadequate personal oral hygiene (OH) are known major risk factors of periodontitis. Nevertheless, the magnitude of their effects has not yet been the subject of a meta-analysis. Material and methods: The Medline and Scopus databases were searched up to May 2016. Observational studies were eligible if they assessed associations between OH and periodontitis in adult subjects. A multivariate random-effects meta-analysis was used to pool the effects of fair/poor OH versus good OH on periodontitis across studies. The associations between oral care habits and periodontitis were also assessed. Results: A total of 50 studies were eligible; 15 were used for pooling the effect of fair OH versus good OH and poor OH versus good OH on periodontitis, with pooled odds ratios (ORs) of 2.04 [95% confidence interval (CI): 1.65–2.53] and 5.01 (95% CI: 3.40–7.39), respectively. Eleven studies examined oral care habits measured according to toothbrushing regularity and dental visit frequency; pooled ORs of 0.66 (95% CI: 0.47–0.94) and 0.68 (95% CI: 0.47–0.98) were obtained, respectively. Conclusions: Fair to poor OH increases the risk of periodontitis by two- to five-fold. This risk can be reduced by regular toothbrushing and dental visits.

Key words: Meta-analysis, oral hygiene, periodontitis, risk factor, systematic review

INTRODUCTION

Periodontitis is the most common oral disease worldwide, with an age-standardised prevalence of 11.2%1. It is a multifactorial disease2, with risk factors such as diabetes mellitus (DM), smoking and, most commonly, inadequate oral hygiene (OH)3. The accumulation of dental plaque and calculus is usually caused by improper toothbrushing techniques, failure to carry out interdental cleaning and irregular dental visits. This accumulation predictably results in gingival inflammation. Persistent gingivitis is a key risk predictor for the breakdown of periodontal attachment. Although poor OH is a well-accepted and important risk factor for periodontitis, the magnitude of the association between OH and periodontitis has not yet been explored in a meta-analysis. Therefore, we conducted a systematic review and meta-analysis aiming to estimate the effects of OH on periodontitis, as measured by the Oral Hygiene Index (OHI), Plaque Index (PI) and plaque score (PSc). A second aim was to pool the magnitudes of association between oral care habits (regular toothbrushing, interdental cleaning and dental visits) and periodontitis.

METHODS

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines for conducting a meta-analysis were followed4. The checklist is provided in Appendix S1 (PROSPERO registration number: CRD42015019036).

Search strategy

Relevant studies were identified from Medline and Scopus databases, searched up to May 2016 using standardised methodological filters. Search strategies
were mainly constructed based on the primary objective with three domains (i.e. periodontitis, OH and general aspects for observational studies), as follows: (‘periodontitis’ OR ‘periodontal’) AND (‘poor oral hygiene’ OR ‘plaque index’ OR ‘oral hygiene index’ OR ‘plaque score’) AND (‘relation’ OR ‘association’ OR ‘risk factor’). The search terms and strategies are described in Table S1.

Inclusion criteria

Studies were screened based on titles and abstracts; if a decision could not be made based on this information, full papers were reviewed. Any type of observational study (e.g. cohort, case–control or cross-sectional) published in English was included if it met the following criteria: (i) assessed associations between OH and periodontitis in either general or specific types of adult populations; (ii) had at least two outcome groups, namely periodontitis versus non-periodontitis, or mild, moderate and severe periodontitis versus normal periodontium; (iii) assessed OH using standard tools, such as the OHI or Simplified Oral Hygiene Index (OHI-S)⁵, PI⁶, plaque control record/PSc⁷ or a questionnaire including the frequency of brushing, interdental cleaning and dental visits; (iv) reported/possibly calculated the mean and standard deviation (SD) of OH scores among periodontitis groups or a contingency table between non-periodontitis/periodontitis and OH groups. Studies were excluded if they had insufficient data for pooling after contacting the authors for additional data.

Two of three reviewers (A.L., S.R. and S.A.) independently evaluated the studies for eligibility, extracted the data and assessed the risk of bias. Any discrepancies between reviewers were discussed and resolved by consensus.

Study factors

The primary study factor was OH, objectively measured using the OHI, PI or PSc. Secondary study factors were oral care habits, which were subjectively assessed using questionnaires assessing the frequency of toothbrushing, interdental cleaning and dental visits.

Outcome

The outcome of interest was periodontitis, which was defined according to the original studies. The definition of periodontitis was based on periodontal probing depth, clinical attachment level or radiographs without a restricted periodontitis definition.

Data extraction

Study characteristics, including study design (cohort, case–control or cross-sectional), population type (general population or specific disease) and study location (community or hospital) were extracted. Subject characteristics (i.e. percentage of male subjects, smoking habits and the presence of DM) and clinical data (i.e. periodontitis definition and details of OH assessments) were also extracted.

Risk of bias assessment

The quality of the studies was assessed using the modified Newcastle–Ottawa Quality Assessment Scale⁸ (Appendix S2), which considers three domains: the representativeness of the studied subjects; the comparability between groups; and the ascertainment of outcome and exposure. Each domain was graded by assigning stars if there was a low risk of bias. Individual studies were categorised, according to these stars, as having a low, moderate or high risk of bias if the percentage of stars was ≥75%, 50–74% and <50%, respectively.

Statistical analysis

Data were pooled if there were at least two studies reporting the same outcomes and study factors. Data analysis was performed separately according to the type of OH data (i.e. categorical or continuous data), as described below.

For categorical data, the odds ratio (OR) of having periodontitis for fair OH versus good OH (OR₁) and poor OH versus good OH (OR₂), along with their 95% confidence intervals (95% CIs) were estimated for each study. For studies with two or more OH groups, a multivariate random-effects meta-analysis was applied for pooling ORs. This method considers within-study variation using Riley’s method⁹,¹⁰. For studies in which OH was divided into more than two groups and ORs were reported without frequency data, the variance-covariance was assumed to be zero.

For continuous data, the mean difference in OH scores between periodontitis and non-periodontitis groups was estimated and pooled using a standardised mean difference (SMD). If logistic model correlation coefficients were reported instead of the mean and SD, the beta coefficients were then pooled using the pooling mean method.

Heterogeneity was assessed using Cochrane’s Q test and the I² statistic. If heterogeneity was present (Q test <0.1 or I² ≥ 25%), a random-effects model (DerSimonian and Laird)¹¹ was used. Otherwise, a fixed-effects model was applied using the inverse variance method.
Sources of heterogeneity were explored using a Galbraith plot to identify outlier studies. Covariates (i.e. population type, age, gender, smoking, DM, index use, periodontitis definition) were then fitted one-by-one into a meta-regression model. If there was a suggested association, a sensitivity analysis excluding the outlier studies and/or a subgroup analysis was performed.

Finally, potential publication bias was explored using the Egger test and a funnel plot. If either of these indicated asymmetry, a contour-enhanced funnel plot was constructed to identify the cause of asymmetry. All analyses were performed using STATA software version 14 (StataCorp, College Station, TX, USA). Two-sided \( P < 0.05 \) was considered statistically significant except for the heterogeneity test, in which \( P < 0.10 \) was used.

Grade of evidence

The system from the Grades of Recommendation, Assessment, Development and Evaluation Working Group (GRADE Working Group)\(^{12,13} \) was used for grading the quality of evidence mainly based on the study design, risk of bias, indirectness of evidence, publication bias, heterogeneity and imprecision of results.

RESULTS

Identifying studies

A total of 2,763 studies were identified from Medline and Scopus, and 1,934 studies remained after removing duplicates. Of these, 1,878 studies were ineligible for reasons described in Figure 1, leaving 56\(^{14-69} \) that were eligible for review. Six studies\(^{14,47,48,51,52,57} \) were excluded because of insufficient data after contacting the authors. Of the remaining 50 studies, 45\(^{15-18,20-31,33,35-39,42-46,49,50,53-56,58-69} \) objectively assessed OH using an oral examination. Of these 45 studies, 15\(^{15,17,22,26-29,31,35-39,46,65} \) analysed OH as categorical data, 31\(^{16,18,20-25,30,33,42-45,49,50,53-56,58-64,66-69} \) as continuous data and one\(^{22} \) as both. Eleven studies provided the association between periodontitis and oral care habits measured according to the frequency of brushing\(^{29,32-34,36,37,40,41,44,56} \), interdental cleaning\(^{29,41,44,56} \) and dental visits\(^{19,33,34,36,40,56} \).

Subject characteristics

The characteristics of the 50 included studies are described in Table 1. Most study designs were cross-sectional, most studies investigated a general population and 34 were based in hospitals. The mean subject age ranged from 15 to 65 years. The percentages of male subjects, smokers and people with diabetes are also shown in Table 1. While the definition of periodontitis varied across the studies, most (92%) used periodontal probing depth and/or clinical attachment level.

Risk of bias assessment

The results of the risk of bias assessments are described in Table S2. Most (72%) studies provided inadequate details for sample selection; hence, representativeness was unclear. For example, some authors did not mention their sampling methods or clearly describe their process for selecting cases and controls. Twenty-seven (46%) studies were potentially biased because of improper statistical adjustments for confounding factors. Almost all studies measured periodontitis via an oral examination, which was objective and valid. However, 16 (32%) studies used partial-mouth examination protocols, 16 (32%) studies diagnosed periodontitis without data regarding clinical attachment level and 25 (50%) studies did not provide details about intra/interexaminer agreement. The numbers of studies with low, moderate and high risks of bias were 23, 19 and 8, respectively.

Oral hygiene

Of the 15 studies which reported OH as categorical data, six\(^{15,29,33,38,46,65} \) categorised OH as good or poor, whereas nine\(^{17,22,26-28,31,36,37,39} \) categorised OH as good, fair or poor. The criteria for classifying OH are presented in Table S3. Pooled In(ORs) determined using a multivariate meta-analysis (Figure 2) were 0.71 (95% CI: 0.50–0.93) and 1.61 (95% CI: 1.22–2.00), which yielded pooled ORs of 2.04 (95% CI: 1.65–2.53) and 5.01 (95% CI: 3.40–7.39), respectively, for fair OH and poor OH. These results indicate that fair OH and poor OH increase the risk of periodontitis by approximately two- and five-fold compared with good OH with an \( I^2 \) of 40% and 78%, respectively. The details of each individual study are shown in Table S4.

Population type appeared to be a large source of heterogeneity. Subgroup analyses in community-based studies yielded lower heterogeneity levels [i.e. the \( I^2 \) values were 4% and 0% for fair and poor versus good OH, respectively, with corresponding pooled ORs of 2.23 (95% CI: 1.85–2.69) and 4.78 (95% CI: 4.10–5.58)]. In addition, a sensitivity analysis focussing on 11 studies\(^{15,17,22,26-29,35-37,39} \) of general populations decreased the degree of heterogeneity to 22% and 49% for fair OH versus good OH and poor OH versus good OH, with pooled ORs of 2.10 (95% CI: 1.76–2.49) and 4.21 (95% CI: 3.21–5.51), respectively. Moreover, the periodontitis definitions and
index types used, as well as smoking behaviour, also contributed to heterogeneity (Table S5).

Among 31 studies that measured OH on a continuous scale, 25\(^\text{18,24,25,33,42–45,49,50,53–56,58–64,66–69}\) compared OH between periodontitis and non-periodontitis groups using the mean scores. The SMDs were highly heterogeneous \((I^2 = 95.6\%)\), with a pooled SMD of 2.04 \((95\% \text{ CI: 1.59–2.50)}\) (Table S6). From these findings, it could be interpreted that periodontitis subjects had a significantly higher OH score of 2.04 standardised units than did non-periodontitis subjects.

Six\(^\text{20,22,25,30,33,42}\) and three\(^\text{16,21,23}\) studies reported the effects of PI and PSc on periodontitis as coefficients \([\text{i.e. ln(OR)}]\) of logistic regression models. Pooling these corresponding effects yielded pooled ORs of 2.25 \((95\% \text{ CI: 1.43–3.54)}\) and 1.02 \((95\% \text{ CI: 1.01–1.03)}\), and high heterogeneity was found for both (Figure 3). These findings could be interpreted to indicate that each one-unit increase in the measures of PI and PSc would increase the odds of having periodontitis by 2.25 and 1.02, respectively.

**Oral health-care habits**

Ten\(^\text{29,32–34,36,37,40,41,44,56}\), four\(^\text{29,41,44,56}\) and six\(^\text{19,33,34,36,40,56}\) studies assessed the effects of brushing, dental floss and dental visits on periodontitis.
| Authors        | Study type      | Study base      | Population  | OH measurement | Age  | Male (%) | Smoking (%) | DM (%) | Periodontitis definition                                                                 |
|----------------|-----------------|-----------------|-------------|----------------|------|----------|-------------|--------|----------------------------------------------------------------------------------------|
| Imaki^15       | Cross-sectional | Community       | General     | PI             | 38.1 | 100      | 56.1        | N/A    | CPITN: 3–4                                                                                   |
| Norderyd^16    | Cross-sectional | Community       | General     | PI             | 38.1 | 100      | 56.1        | N/A    | Radiography: bone loss more than one-third of root length                                    |
| Wakai^17       | Cross-sectional | Hospital        | General     | PI             | 51.1 | 82.1     | 34.4        | N/A    | CPITN: 3–4                                                                                   |
| Papapanou^18   | Case-control    | Hospital        | General     | PI, PSc        | 50.9 | 47.3     | 32.2        | N/A    | One site or more with PPD ≥5 mm AND CAL ≥3 mm                                              |
| Hashim^19      | Cohort          | Community       | General     | OHI, Dental visit | 15   | 54.2     | 33.3        | N/A    | One site or more with ≥4 mm increase in CAL                                                  |
| Teal^20        | Cross-sectional | Community       | General     | PI             | 48.7 | 48.2     | 61.8        | N/A    | Mean CAL ≥2 mm                                                                               |
| Hugoson^21     | Cross-sectional | Community       | General     | PSc            | 65.0 | 52.7     | 42.9        | N/A    | Radiography: bone loss more than one-third of root length                                    |
| Do^22          | Cross-sectional | Community       | General     | PI, PSc        | 40   | 40.3     | 28.9        | N/A    | Two or more sites with CAL ≥5 mm AND one site or more with PPD ≥4 mm                         |
| Meisel^23      | Cross-sectional | Community       | General     | PSc            | 51.0 | 46.6     | 49.5        | 6      | 4th–5th quartiles of the percentage of sites with CAL ≥4 mm                                  |
| Alpagot^24     | Cohort          | Hospital        | Patients with HIV | PI             | 34.1 | 57.9     | N/A         | 0      | One site or more with PPD ≥4 mm OR CAL ≥2 mm                                                 |
| Solis^25       | Cross-sectional | Hospital        | General     | PI             | 37.4 | 35.3     | 23.0        | 0      | Two or more sites with CAL ≥6 mm AND one site or more with PPD ≥5 mm                         |
| Wickholm^26    | Cross-sectional | Community       | General     | PI             | 36.7 | 49.2     | 44.7        | N/A    | Three or more teeth with PPD ≥5 mm                                                            |
| Natto^27       | Cross-sectional | Community       | General     | PI             | 36.4 | 64.9     | 70.0        | N/A    | ≥10 sites with PPD ≥5 mm                                                                       |
| Torrungruang^28| Cross-sectional | Community       | General     | PSc            | 60   | 74.4     | 14.3        | 15.8   | Mean CAL ≥2.5 mm                                                                              |
| de Macedo^29   | Cross-sectional | Community       | General     | PSc, Flossing, Brushing | N/A  | 33.8     | 31.4        | N/A    | Four or more teeth with PPD ≥4 mm AND CAL ≥3 mm at the same site                              |
| Khader^30      | Cross-sectional | Hospital        | General     | PI             | 39.4 | 44.8     | N/A         | N/A    | Khader’s risk score                                                                          |
| Vandana^31     | Cross-sectional | Hospital        | Dental fluorosis | PI, Flossing, Brushing | 25.36 | 68.6     | N/A         | 0      | CPITN: 3–4                                                                                   |
| Wang^32        | Cross-sectional | Hospital        | General     | PI             | 38.5 | 50       | 45.7        | N/A    | Two or more sites with CAL ≥6 AND one site or more with PPD ≥5 mm                             |
| Akhter^33      | Case-control    | Hospital        | General     | PI, Brushing, Dental visit | 33.9 | 100      | N/A         | N/A    | CPITN: 3–4                                                                                   |
| Kumar^34       | Cross-sectional | Community       | General     | PI, Brushing, Dental visit | 58   | 54.9     | 19.2        | 6.7    | CDG/AAP                                                                                      |
| Benguigui^35   | Cross-sectional | Community       | General     | PI             | 41.86| 27       | 0           | 0      | New teeth with PPD ≥4 mm                                                                      |
| Saxlin^36      | Cohort          | Community       | General     | PI, Brushing, Dental visit | 36.4 | 49.4     | 20.3        | 17.9   | Four or more teeth with PPD ≥4 mm AND CAL ≥3 mm at the same site                              |
| Bawadi^37      | Cross-sectional | Hospital        | General     | PI, Brushing, Dental visit | 45.7 | 59.7     | 42.7        | N/A    | One site or more with PPD >4 mm                                                               |
| Carrilho Neto^38| Cross-sectional | Hospital        | Inpatients  | OHI            | 45.7 | 57.3     | N/A         | N/A    | N/A                                                                                          |
| Mathur^39      | Cross-sectional | Hospital        | General     | OHI            | N/A  | 57.3     | N/A         | N/A    | N/A                                                                                          |
| Teng^40        | Cross-sectional | Hospital        | Psychiatric inpatients | PI, Brushing, Dental visit | 41   | 62.5     | 42.5        | N/A    | CPITN: 3–4                                                                                   |
| Crocombe^41    | Cross-sectional | Community       | General     | PSc            | N/A  | 50       | 15          | 4.3    | One site or more with CAL ≥4 mm                                                               |
| Mannem^42      | Cross-sectional | Hospital        | General     | PI             | 52.5 | 44.1     | 34.2        | N/A    | Four or more teeth with PPD ≥4 mm AND CAL ≥3 mm at the same site                              |
| Raja^43        | Cross-sectional | Hospital        | General     | PI, PSc        | 36.5 | 53.3     | 96.7        | 0      | Four or more sites with CAL ≥4 mm                                                            |
| Vogt^44        | Cross-sectional | Hospital        | Pregnancy   | PI, PSc        | 27.2 | 0        | 15.87       | 0      | Four or more teeth with PPD ≥4 mm AND CAL ≥4 mm at the same site                              |
| Fiyaz^45       | Case-control    | Hospital        | General     | OHI            | N/A  | N/A      | 0           | 0      | One site or more with PPD >4 mm OR CAL >1.5 mm                                               |
| Palle^46       | Cross-sectional | Hospital        | CVD          | OHI            | 57.2 | 84.1     | 32.3        | 52.2   | Five or more sites with CAL ≥5 mm                                                             |
| Catmak^49      | Case-control    | Hospital        | General     | PI             | 38.3 | 49.1     | 0           | 0      | One site or more with PPD ≥5 mm AND CAL ≥4 mm                                               |
| Develioglu^50  | Case-control    | Hospital        | General     | PI             | 46.7 | N/A      | 33.3        | 0      | ≥30% sites with PPD ≥5 mm AND CAL ≥3 mm                                                       |

(continued)
| Authors | Study type | Study base | Population | OH measurement | Age | Male (%) | Smoking (%) | DM (%) | Periodontitis definition |
|---------|------------|------------|------------|---------------|-----|----------|-------------|-------|-------------------------|
| Jacob\textsuperscript{33} | Case-control | Hospital | General | PI | 37.3 | 75.6 | 33.3 | 0 | CDC/AAP |
| Kaur\textsuperscript{34} | Case-control | Hospital | General | PI | N/A | 66.7 | 25 | 0 | N/A |
| Koseoglu\textsuperscript{35} | Case-control | Hospital | General | PI | 34.0 | 50 | 0 | 0 | Four or more teeth with PPD ≥5 mm AND CAL ≥4 mm in each jaw |
| Kovačević\textsuperscript{36} | Cross-sectional | Hospital | General | OHI, Brushing, Flossing, Dental visit | 38.9 | 77.2 | 31.7 | N/A | CPITN: 3–4 |
| Lavu\textsuperscript{38} | Case-control | Hospital | General | OHI | 33.6 | 50.4 | 0 | 0 | CAL >1 mm at least 30% sites |
| Luthioglu\textsuperscript{39} | Case-control | Hospital | General | PI | 33.1 | 53.3 | 51.1 | 0 | One site or more with PPD ≥5 mm with radiographic evidence of bone loss |
| Meenawat\textsuperscript{40} | Case-control | Hospital | General | PI | 43.2 | 100 | 41.4 | 0 | Four or more teeth with PPD >4 mm AND CAL >2 mm |
| Meza\textsuperscript{41} | Case-control | Hospital | General | PSc | 46.3 | 40.3 | 46.8 | N/A | Four or more teeth with PPD ≥4 mm AND CAL ≥3 mm at the same sites |
| Perayil\textsuperscript{42} | Case-control | Hospital | General | OHI | 43.1 | 43.3 | 0 | 0 | Five or more teeth with PPD ≥5 mm AND CAL ≥3 mm |
| Pereira\textsuperscript{43} | Case-control | Hospital | General | PSc | 38.4 | 33.7 | 0 | 0 | Four or more teeth with PPD ≥4 mm AND CAL ≥3 mm |
| Petrovic\textsuperscript{44} | Case-control | Hospital | General | PI | 36.1 | 38.8 | 22.4 | 0 | Three or more quadrants with three or more sites with PPD ≥3 mm AND CAL ≥2 mm |
| Pranckeviciene\textsuperscript{65} | Cross-sectional | Hospital | Type I and type II DM | PI | 43.86 | N/A | 25.9 | 100 | One site or more with CAL >5 mm |
| Puri\textsuperscript{66} | Case-control | Hospital | General | OHI | 39.78 | N/A | 0 | 0 | AAP 1999 |
| Singh\textsuperscript{67} | Case-control | Hospital | General | PI | 43.5 | 52.5 | 0 | 0 | One site or more with PPD ≥5 mm AND CAL ≥2 mm |
| Toyman\textsuperscript{68} | Case-control | Hospital | General | PI | 34.6 | 51.2 | 0 | 0 | Six teeth or more with PPD ≥5 mm with radiographic evidence of bone loss |
| Varghese\textsuperscript{69} | Case-control | Hospital | General | PI | N/A | 65.3 | 0 | 0 | ≥30% sites with PPD ≥6 mm AND CAL ≥5 mm |

CAL, clinical attachment level; CDC/AAP, periodontitis definition of the Centers for Disease Control and Prevention in collaboration with the American Academy of Periodontology; CPITN, the Community Periodontal Index of Treatment Needs; CVD, cardiovascular disease; DM, diabetes mellitus; HIV, human immunodeficiency virus; N/A, not available; OH, oral hygiene; OHI, oral hygiene index; PI, plaque index; PPD, periodontal pocket depth; PSc, plaque score.
The pooled ORs (Figure 4) suggested that toothbrushing and dental visits were significantly associated with periodontitis, although the I² values showed high heterogeneity, at 94.5% and 60.4%, respectively. Subjects who brushed their teeth regularly had approximately 34% significantly lower odds of having periodontitis (pooled OR = 0.66; 95% CI: 0.47–0.94). Smoking, the definition of regular brushing and periodontitis were potential sources of heterogeneity (Table S8).

For dental visits, the sensitivity analysis was performed by considering four of six studies that had clearly defined a regular dental visit as at least one visit per year19,33,36,56. This yielded a significant effect size of 0.56 (95% CI: 0.37–0.83) with an I² of 9%, indicating that subjects who regularly visited dentists at least once a year had a 44% lower risk of periodontitis than those who did not. The effects of interdental cleaning with dental floss on periodontitis showed little heterogeneity (I² = 5.1%), but the pooled OR was borderline significant (OR = 0.87; 95% CI: 0.75–1.00).

### Publication bias

Publication bias was assessed for all pooled estimates using funnel plots (Figure S1) and Egger tests (Table S9). The results suggested symmetry except for the mean differences in OH score, PSc and dental visits. Contour-enhanced funnel plots were further constructed (Figure S2), and these indicated that the asymmetry of the funnels might be caused by both heterogeneity and publication bias.

### Quality of evidence

The scoring using the GRADE framework is shown in Table 2 and Appendix S3. Based on observational studies, all pooled estimates were graded as low quality13. For the effects of fair OH and poor OH on periodontitis, this was upgraded to moderate quality because of large effect sizes and strong dose–response relationships. The effects of brushing and dental visits were downgraded to very low quality caused by heterogeneity and publication bias, respectively.
DISCUSSION

We conducted a systematic review and meta-analysis of the effects of OH on periodontitis. The results suggest a dose–response relationship between OH and periodontitis, with fair and poor OH significantly increasing the risk of having periodontitis by two- and five-fold, respectively, compared with good OH. In contrast, regular toothbrushing and dentist visits could reduce periodontitis by 34% and 32%, respectively. These pooled OH effects and oral care habits are summarised in Table 2 and Figure 5.
The effect of OH on periodontitis was stronger than those of other risk factors, such as DM\textsuperscript{70} (OR = 2.6; 95% CI: 1.0–6.6), smoking\textsuperscript{71} (OR = 2.82; 95% CI: 2.36–3.39) or obesity\textsuperscript{72} (OR = 2.13; 95% CI: 1.40–3.26). Our results also showed protective effects of regular toothbrushing, which were consistent with the findings of a previous meta-analysis\textsuperscript{73} that reported a significant risk for severe periodontitis caused by infrequent brushing (OR = 1.44; 95% CI: 1.21–1.71). However, our study could only identify a small effect of interdental cleaning with dental floss (i.e. a non-significant reduction of 13% in the risk of periodontitis). This result was also consistent with a previous meta-analysis\textsuperscript{74}, which found little benefit from self-performed flossing on plaque or periodontal parameters.

Although the use of OH assessments varied between the included studies, approximately half commonly used the PI with similar cut-off points. OH was defined as poor for a PI of >2 or if the patient had a moderate accumulation of soft deposits visible by the naked eye; and OH was defined as fair for PI values ranging from 1 to 2 or if the patient had a film of plaque adhering to the tooth as detected by disclosing solution or probe.

To address concerns about the varying quality of the individual studies, a sensitivity analysis was also performed, including only studies with a low risk of bias\textsuperscript{22,26–29,33–37,46,65}. The results showed little difference compared with those of the main analysis, but heterogeneity was much lower.

Good OH and oral care habits should be encouraged and promoted in public health campaigns. Dentists and dental hygienists should regularly educate, motivate and assess patients’ perceptions for improving oral health behaviours. Additionally, dental nurses or assistants should encourage and provide general, useful information. Repeated and individually tailored OH instructions are key elements in achieving gingival health. Goal setting, self-monitoring and planning are effective interventions for improving OH-related behaviours in patients with periodontitis. Recognising the benefits of behaviour changes, their own susceptibility and the deleterious effects of periodontitis are important messages in periodontitis prevention\textsuperscript{75}.

Patients should be able to access dental care regularly for professional cleaning together with tailoring and monitoring their OH\textsuperscript{75}. They should also be taught how to perform plaque removal efficiently. Generally, mechanical plaque controlled by twice-

Table 2 Overview of the meta-analysis

| Risk factor                      | No. of studies | Pooled OR (95% CI) | I\textsuperscript{2} (%) | Quality of evidence* |
|----------------------------------|----------------|--------------------|--------------------------|----------------------|
| **OH**                           |                |                    |                          |                      |
| Categorical data                 |                |                    |                          |                      |
| Fair OH versus Good OH           | 9              | 2.04 (1.65–2.53)   | 40                       | Low                  |
| Good OH                          | 15             | 5.01 (3.40–7.39)   | 78                       | Low                  |
| Continuous data                  |                |                    |                          |                      |
| PI: 1-unit increase              | 6              | 2.25 (1.43–3.54)   | 81.1                     | Moderate             |
| PSc: 1-unit increase             | 3              | 1.02 (1.01–1.03)   | 74.2                     | Low                  |
| OH score                         | 25             | 2.04 (1.59–2.50)†  | 95.6                     | Moderate             |
| Oral health-care habits          |                |                    |                          |                      |
| Toothbrushing                    | 10             | 0.66 (0.47–0.94)   | 94.5                     | Very low             |
| Interdental cleaning             | 4              | 0.87 (0.75–1.00)   | 5.1                      | Low                  |
| Dental visits                    | 6              | 0.68 (0.47–0.98)   | 60.4                     | Very low             |

OH, oral hygiene; PI, plaque index; PSc, plaque score. *Quality of evidence: The Grades of Recommendation, Assessment, Development and Evaluation Working Group (GRADE Working Group). †Pooled standard mean difference (SMD).

Figure 5. Summary of pooled effect of oral hygiene (OH) and oral care habits on periodontitis. OR, odds ratio.
daily toothbrushing with a fluoride-containing dentifrice is an accepted recommendation. The proper duration of toothbrushing is also mentioned as an important determinant of plaque removal; therefore, it should be stressed during toothbrushing instruction. The current scientific data show that dental floss is not effective as a tool for removal of interdental plaque; however, brushes have been shown to be the most effective specific skills in order to be more effective. Interdental floss is not effective as a tool for removal of interdental plaque. The selection of interdental aids must be at the clinician’s discretion based on a patient’s needs and dexterity and the characteristics of a patient’s interdental spaces.

This study has some strengths. It includes studies of the effects of OH using both objective and subjective assessments. The magnitudes of the effects were pooled and reported. The results of subgroup analyses (i.e. population type, study base, periodontitis definition and smoking) were also explored. We used rigorous pooling methods (multivariate random-effects meta-analysis), which considered the variance-covariance between the studies.

However, this study also has some limitations. Our pooled ORs were based on summary data of observational studies. Some data were reported without adjusting for potential confounders; thus, the pooled results might be prone to bias. Moreover, the definition of periodontitis varied among studies, which resulted in high heterogeneity, although the subgroup analyses did reduce this effect. Furthermore, the assessments of publication bias using funnel plots and Egger tests with the low numbers of included studies in some meta-analyses may not be valid. Failure to detect asymmetry cannot rule out a reporting bias or vice versa.

In conclusion, poor OH increases the risk of periodontitis by approximately two- to five-fold compared with good OH. Oral care habits, including regular brushing and dental visits, can decrease the risk of periodontitis and should thus be promoted as a public health intervention.

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Conflicts of interest

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Funnel plots of publication bias assessment.
Figure S2. Contour-enhanced funnel plots.
Table S1. Search terms and search strategy.
Table S2. Risk of bias assessment.
Table S3. Categorisation of OH level.
Table S4. Pooling effects of fair and poor versus good OH on periodontitis.
Table S5. Subgroup and sensitivity analysis according to sources of heterogeneity of fair and poor versus good OH.
Table S6. Pooling SMD of OH scores between periodontitis and non-periodontitis.
Table S7. Pooled effect size of oral care habits on periodontitis.
Table S8. Sources of heterogeneity of tooth brushing meta-analysis.
Table S9. Publication bias assessment by Egger test.
Appendix S1. PRISMA checklist.
Appendix S2. Modified Newcastle-Ottawa Quality Assessment Scale.
Appendix S3. GRADE approach.

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Correspondence to: Sasivimol Rattanasirist, Section for Clinical Epidemiology and Biostatistics, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, 270 RAMA VI Road, Rachathewi, Bangkok 10400, Thailand. Email: sasivimol.rat@mahidol.ac.th