Japanese Dental Science Review 60 (2024) 163–174

Contents lists available at ScienceDirect

Japanese Dental Science Review

journal homepage: www.elsevier.com/locate/jdsr

The clinical efficacy of powder air-polishing in the non-surgical treatment of peri-implant diseases: A systematic review and meta-analysis

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ARTICLE INFO

Keywords:
Peri-implant diseases
Non-surgical treatment
Air-polishing
Systematic review

ABSTRACT

Peri-implant diseases, characterized by inflammatory conditions affecting peri-implant tissues, encompass peri-implant mucositis and peri-implantitis. Peri-implant mucositis is an inflammatory lesion limited to the mucosa around an implant, while peri-implantitis extends from the mucosa to the supporting bone, causing a loss of osseointegration. For non-surgical treatments, we tested the null hypothesis that the presence or absence of air-polishing made no difference. The study focused on randomized controlled trials (RCTs) comparing air-polishing with mechanical or ultrasonic debridement, evaluating outcomes such as bleeding on probing (BOP), probing depth (PD), plaque index/plaque score (PI/PS), clinical attachment level (CAL), bone loss, and mucosal recession (MR). Two independent reviewers conducted data extraction and quality assessments, considering short-term (<6 months) and long-term (≥6 months) follow-up periods. After screening, ten articles were included in the meta-analysis. In nonsurgical peri-implant disease management, air-polishing moderately mitigated short-term PI/PS for peri-implant mucositis and showed a similar improvement in long-term BOP and bone loss for peri-implantitis compared to the control group. The Egger test found no evidence of publication bias except for the long-term PI/PS of peri-implant mucositis. Leave-one-out analysis confirmed the stability of the results. The findings highlight the need for future research with longer-term follow-up and high-quality, multi-center, large-sample RCTs.

1. Introduction

Peri-implant diseases encompass inflammatory issues impacting the tissues surrounding dental implants. These conditions can be generally classified into two primary categories: peri-implant mucositis and peri-implantitis [1]. Peri-implant mucositis is a condition marked by soft tissue inflammation due to plaque buildup, without any additional bone loss beyond crestal bone level changes resulting from initial bone remodeling. Conversely, peri-implantitis involves inflammation accompanied by progressive bone loss beyond these initial crestal changes[2,3]. Multiple studies have underscored the role of peri-implant mucositis as a precursor to the more severe condition of peri-implantitis. Appropriate interventions have been demonstrated to be effective in reversing peri-implant mucositis [4,5]. Nevertheless, inadequate treatment may result in lingering inflammation of the soft tissues surrounding the implant, potentially causing irreversible bone loss in the structures supporting the implant and ultimately progressing to peri-implantitis [4]. According to the literature, the prevalence of

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https://doi.org/10.1016/j.jdsr.2024.05.003
Received 26 February 2024; Received in revised form 23 April 2024; Accepted 15 May 2024

peri-implant mucositis is reported to be 43%, with a range from 19% to 65%. In the case of peri-implantitis, the prevalence is noted at 22%, with a range extending from 1% to 47% [6]. Consequently, there has been a growing emphasis on the prevention and treatment strategies for both peri-implant mucositis and peri-implantitis to mitigate their impact on oral health.

In the management of peri-implant diseases, two principal strategies are recognized: surgical and non-surgical interventions. Given its minimally invasive nature, non-surgical therapy is often the preferred initial treatment option [7]. It is advisable to complete non-surgical treatment before considering any surgical interventions [8]. This strategy not only evaluates the effectiveness of non-surgical interventions but also gauges the patient's ability and dedication to maintaining effective oral hygiene practices [9]. Effective procedures for non-surgical treatment encompass a range of methods, such as photodynamic therapy (PDT), antibiotic therapy, power-driven air-polishing devices, lasers, as well as sonic/ultrasonic scalers and manual curettage (constructed from plastic, metal, or titanium) [10–12].

The management of peri-implant diseases centers on the removal of plaque biofilm that adheres to the implant surface. Traditional scraping techniques are often insufficient in dislodging plaque and may inadvertently harm the implant's threads or coatings, which can precipitate further complications[13]. Besides mechanical debridement, many other therapies have been applied to control the inflammation. PDT employs light-activated compounds to eradicate bacteria and reduce inflammation[12]. Laser therapy offers precision, using focused energy to remove diseased tissue, promoting healing, and preserving healthy structures[14]. Antibiotic therapy plays a crucial role by employing local or systemic administration of antibiotics to manage infection and inflammation, thereby supporting the overall health of the dental implant[15]. PDT and laser treatments typically necessitate specialized equipment and photosensitizing agents, potentially resulting in increased costs for the therapy. Additionally, the use of antibacterial medications carries the risk of fostering drug resistance. Therefore, air-polishing emerges as a viable alternative, utilizing a high-velocity stream of a water and abrasive powder mixture to effectively eradicate dental plaque, stains, or pigments from both teeth and implant surfaces. The water's cooling effect also serves to reduce patient discomfort during the procedure [16]. Executed with precision by a skilled surgeon, air-polishing safely cleans the implant surface, avoiding damage [17]. Recent researches have also highlighted the clinical efficacy of air-polishing techniques with specific powders such as sodium bicarbonate, amino-acid glycine, and non-caloric erythritol, demonstrating their potential to yield positive outcomes [18–21]. Nonetheless, the supporting evidence for their application remains limited and somewhat unclear, highlighting the need for additional research to solidify a more comprehensive and robust evidence base.

Recently, a number of systematic reviews have concentrated on assessing the impact of air-polishing on peri-implant mucositis and peri-implantitis [7,22]. However, the systematic review and meta-analysis conducted by Boeira *et al.* incorporated seven related studies, among which two were controlled clinical trials [22]. The robustness of the evidence supporting the conclusions drawn from the meta-analysis may be compromised due to the scarcity of an adequate number of RCTs, potentially increasing the risk of bias [18,22,23]. Another systematic review included two RCTs focused on peri-implantitis for meta-analytical comparison. It is noteworthy that one of these studies designated the laser therapy group as the control, whereas the other study chose the manual curetting group for this role. This inconsistency in the selection of control groups across the studies led to divergent findings within the meta-analysis [7]. Strictly speaking, there is a notable absence of a comprehensive meta-analysis within the existing systematic review literature that thoroughly evaluates the efficacy of air-polishing as a non-surgical treatment modality for both peri-implantitis and peri-implant mucositis.

Thus, a more targeted analysis is imperative for assessing the therapeutic outcomes of air-polishing in addressing peri-implant mucositis and peri-implantitis. Consequently, the primary aim of this systematic review and meta-analysis was to examine the effectiveness of air-polishing therapy with powder compared to mechanical or ultrasonic debridement in patients with peri-implant diseases. Underpinning our study was the null hypothesis that there was no significant difference in outcomes attributable to the application or non-application of air-polishing.

2. Methods

2.1. Patient and public involvement

No patients were involved in the study.

2.2. Study design

This systematic review adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Additionally, it was formally registered in the PROSPERO database under the registration number CRD42023423201 [24].

2.3. Focused question

The current systematic review addresses the following focused question structured in the PICO format: "What is the clinical effectiveness of powder air-polishing as a non-surgical approach compared with mechanical or ultrasonic debridement in maintaining peri-implant health or treating peri-implant disease?" Population: adult patients diagnosed with peri-implantitis or peri-implant mucositis, as defined in the publications, and those with healthy implants; Intervention: any type of powder air-polishing; Comparison: non-surgical implant surface mechanical or ultrasonic debridement; Outcomes: clinical outcomes included changes in bleeding on probing (BOP), probing depth (PD), clinical attachment level (CAL), plaque index/score (PI/PS), bone loss and mucosal recession (MR).

2.4. Search strategy

A comprehensive electronic search was carried out across key databases, including PubMed, Scopus, Cochrane Central Register of Controlled Trials, and Web of Science, up until December 2023 to identify relevant published literature. Gray literature was explored using the System for Information on Grey Literature in Europe and Google Scholar. The detailed search strategies for each database are available in Supplemental File 1. Electronic title management was conducted with the assistance of Endnote X7, and inclusion criteria were limited to articles published in the English language. To mitigate potential data gaps, we contacted corresponding authors as needed. Two independent reviewers conducted the initial screening and assessment of potential articles, resolving any disagreements during the first screening stage through discussions with a third reviewer.

2.5. Study inclusion and exclusion criteria

In the initial phase of study selection, studies were deemed eligible based on the following inclusion criteria: 1) study types: randomized controlled clinical trial (RCT) with a parallel group design or randomized controlled cross-over studies involving human participants; 2) comparison of powder air-polishing versus mechanical or ultrasonic debridement; 3) assessment of clinical data changes related to peri-implantitis and peri-implant mucositis before and after treatment. In the subsequent phase of selection, studies meeting the initial criteria were further refined according to the following exclusion criteria: 1) in vitro and animal studies, letters to the editor, monographs, oral

presentation, interviews, review articles and meta-analyses; 2) unclear identification of peri-implant diseases; 3) studies lacking complete or accessible data even after attempts to contact authors; 4) patients who underwent surgical treatments or antibiotic therapy; 5) follow-up < 1 month.

2.6. Risk of Bias (Quality) assessment

The included studies underwent a quality assessment with the Revised Cochrane Risk of Bias tool for randomized trials (RoB2) [25]. Briefly, an assessment was conducted across five domain areas (randomization, allocation concealment, participants and professionals blinded to the study, blinding of outcome assessment, and other biases). The overall bias was categorized as "high risk of bias" (high), "low risk of bias" (low), or "unclear risk of bias" (?). Following the article screening, two reviewers performed the assessment independently. Any disagreements were resolved by consulting with a third reviewer.

2.7. Data extraction and data item

Data and information from the included articles were retrieved and collected into the predesigned table by two reviewers independently: 1) study identification: author's name, the year of publication; 2) study type; 3) population: numbers of patients, numbers of implants; 4) definition of peri-implant diseases; 5) type of intervention: details of powder air-polishing; 6) clinical outcomes (i.e., BOP, PD, PI/PS, CAL, bone loss and MR); 7) follow-up. Clinical evaluations intended for extraction included clinical outcomes such as BOP, PD, PI/PS, CAL, bone loss, and MR.

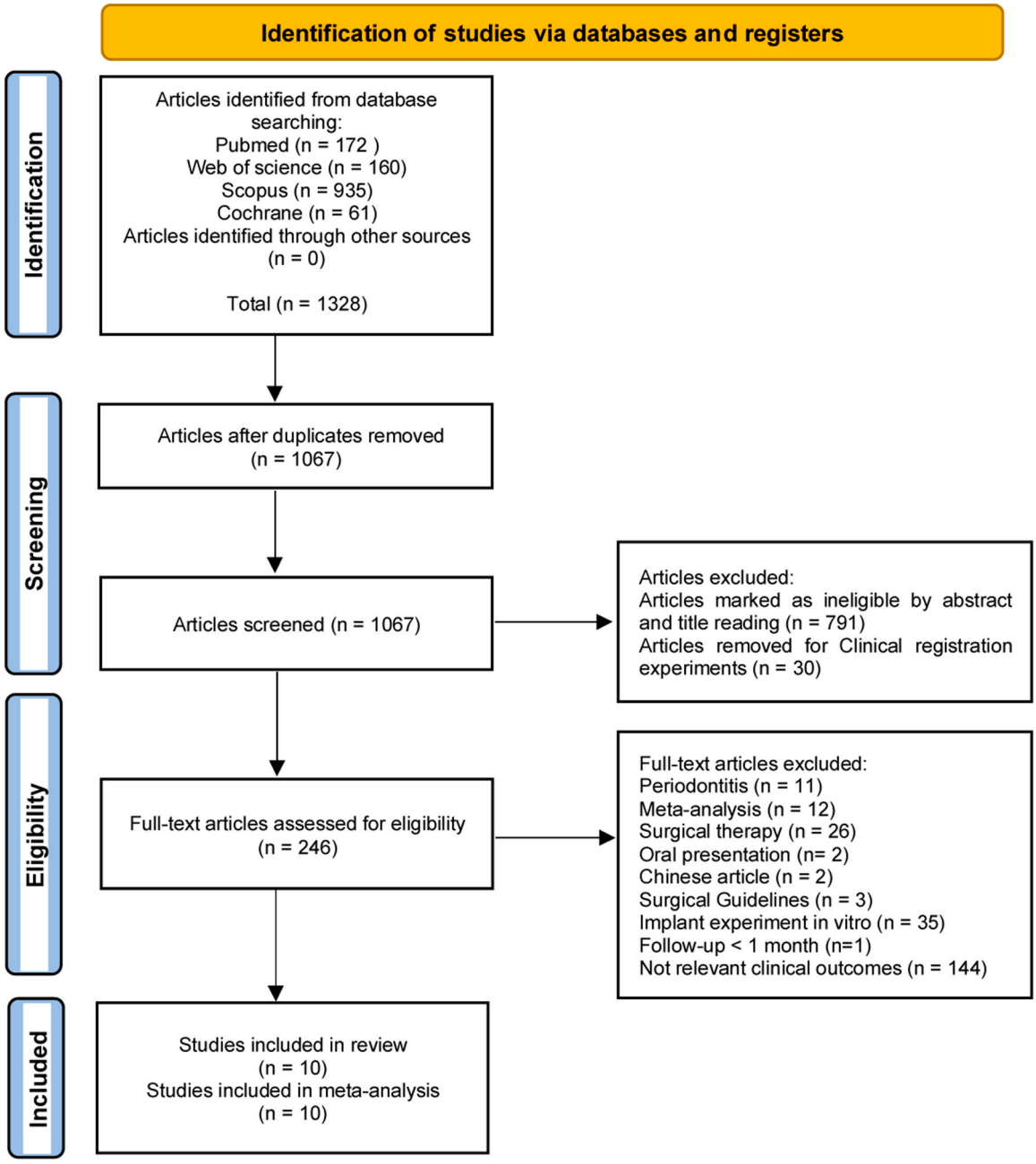

Fig. 1. Flow diagram of literature search strategy and inclusion and exclusion criteria.

2.8. Statistical analysis

The statistical analysis was conducted utilizing the Review Manager 5.3 and Stata 17. The assessment of statistical heterogeneity among studies involved both the Q and I^2 tests. A Q statistic p-value below 0.1 was deemed indicative of heterogeneity. The interpretation of I^2 values followed this classification: 0–30% for low heterogeneity, 30–60% for moderate heterogeneity, and > 60% for substantial heterogeneity. If I^2 exceeded 50% or the p-value was less than 0.10, it was recommended to perform a subgroup analysis to investigate the sources of heterogeneity [26,27]. Differences between the experimental and control groups were expressed as the weighted mean difference (WMD) with 95% confidence interval (CI) and the standardized mean difference (SMD) with 95% CI, using the random effect models. For continuous outcomes, the collection of mean differences and standard deviations was necessary. In cases where data were not presented as mean differences, the mean difference was computed, and the standard deviation was estimated using the formula: $r_d = \text{sqrt}\ (r_1^2/n_1 + r_2^2/n_2)$. An objective assessment of publication bias was conducted through Egger's tests, where a p-value < 0.05 indicated the presence of publication bias [5]. To evaluate result stability, sensitivity analysis (leave-one-out analysis) was performed by sequentially excluding individual studies [28].

3. Result

3.1. Study selection

Initially, a total of 1328 articles were potentially identified through a combination of electronic and manual searches. Following the removal of duplicates, 246 articles were retained based on screening titles and abstracts. Subsequently, a thorough evaluation of the full texts was conducted, resulting in the inclusion of ten articles for review [18–21,23,29–33] (Fig. 1).

3.2. Study characteristics

Table 1 provided a comprehensive overview of the primary characteristics of the included studies. All selected studies were RCTs and were published in English up to December 2023. The follow-up duration ranged from 1 month to 12 months. Remarkably, Riben *et.al.* performed repeated treatments at 3 and 6 months, while Selimović' *et.al.* and Ghazal *et.al.* conducted treatments at 3, 6, 9, and 12 months [20,29,32]. In contrast, other studies exclusively carried out interventions at the baseline [18,19,21,23,30,31,33]. All subjects received oral hygiene instruction. All treatments were performed under local anesthesia in the two studies [18,21]. For the readers' convenience, detailed information on the specific criteria used in each study to diagnose peri-implant diseases was presented in Table 1.

3.3. Risk of bias

A study was assessed to have an unclear risk of bias due to the absence of random sequence generation [18]. Two studies were deemed to have an unclear risk of bias as they did not provide proper allocation concealment [18,23]. Regarding attrition bias, the trial conducted by Riben *et al.* was categorized as high risk due to the lack of BOP data at 1 month [20]. In terms of selective reporting (reporting bias), the trial conducted by Hentennar *et al.* was considered high risk because only patients who demonstrated success at 3 months were subjected to additional testing at 6, 9, and 12 months [21]. In the category of other bias, three studies were identified as having a high risk of bias due to research funding provided by the air-polishing device company [18,21,31]. In addition, three other studies were labeled as having an unclear risk of bias due to the absence of funding information [20,23,29,33] (Fig. 2).

3.4. Study outcomes

3.4.1. Peri-implant mucositis

In the study conducted by Lupi *et al.*, a notable variance in BOP, PD, and PI changes ($P < 0.05$) at 6 months was observed between the experimental group and the control group, while CAL changes did not demonstrate a statistically significant difference [19]. In the other four studies included, no significant disparities in related clinical outcomes were reported between the experimental group and the control group [20,29–31].

3.4.2. Peri-implantitis

Regarding BOP, two studies revealed a noteworthy distinction ($P < 0.05$) between the air-polishing group and the control group [18,23]. Conversely, the remaining studies did not indicate any significant differences. In terms of PD, PI/PS, CAL, bone loss, and MR, none of the five included studies demonstrated a significant distinction between the two groups [18,21,23,32,33].

3.5. Meta-analysis

A meta-analysis was conducted on studies examining clinical outcomes related to BOP, PD, PI/PS, and CAL in the context of peri-implant mucositis. In the short term (<6 months), the SMD in BOP changes between the experimental and control group was 0.11 (95% CI −0.07 to 0.30, p = 0.22), indicating no significant preference for air-polishing treatment. Similar non-significant results were observed for PD changes (WMD = −0.05; 95% CI −0.19 to 0.09, p = 0.51). However, there was a significant difference in PI/PS changes (SMD = −1.17, 95% CI −1.99 to −0.34, p = 0.006). In the long term (≥6 months), no significant differences were found in BOP changes (SMD = 0.03; 95% CI −0.17 to 0.24, p = 0.75), PD changes (WMD = −0.30; 95% CI −1.07 to 0.48, p = 0.45), and PI/PS changes (SMD = −0.52; 95% CI −1.31 to 0.28, p = 0.20). Additionally, The WMD in CAL changes at peri-implant mucositis between the experimental and control group was − 0.24 (95% CI −0.53 to 0.06, p = 0.12). Substantial heterogeneity was noted for each outcome, except for the changes in BOP and CAL ($I^2 = 0\%$) (Fig. 3).

For studies related to peri-implantitis in the short term (<6 months), the SMD in BOP changes between the experimental and control groups was − 0.47 (95% CI −1.46 to 0.52, p = 0.35), indicating no significant favor towards air-polishing treatment. Similar non-significant results were observed for PD (WMD = −0.10; 95% CI −0.46 to 0.26, p = 0.57), PI/PS (SMD = −0.09; 95%CI −0.39 to 0.20, p = 0.54), CAL (WMD = 0.10; 95% CI −0.66 to 0.86, p = 0.80), bone loss (WMD = −0.10; 95% CI −0.72 to 0.52, p = 0.75) and MR (WMD = 0.10; 95% CI −0.50 to 0.70, p = 0.74). In the long term (≥ 6 months), BOP exhibited a significant reduction in the experimental group compared with the control group (SMD = −1.00, 95% CI −1.75 to −0.25, p = 0.009). The alteration in bone loss also revealed a statistically significant difference (WMD = −0.27, 95% CI −0.48 to −0.06, p = 0.01). However, there were no significant differences between the experimental and control groups in terms of PD (WMD = 0.15, 95% CI −0.03 to 0.32, p = 0.09), PI/PS (SMD = 0.48, 95% CI −0.26 to 1.23, p = 0.20), CAL (WMD = −0.00, 95% CI −0.53 to 0.53, p = 1.00), MR (WMD = 0.11, 95% CI −0.22 to 0.44, p = 0.50). Substantial heterogeneity was observed for each outcome, except for PD changes (<6 months), PI/PS changes (<6 months), CAL changes, and MR changes (Fig. 4). Given the variation in polishing powders utilized, a subgroup analysis was performed based on the specific powder employed. The findings indicated that glycine demonstrated a notably superior effectiveness compared to erythritol in reducing BOP. However, no statistically significant differences were observed in other clinical outcomes (Fig. S1). Table 2 shows the quantitative results of the included studies for each outcome.

Table 1
Characteristics of the included studies.

Study	Type	Population	Case definition	Test group	Control group	outcomes	Follow-up
Peri-implantitis							
Sahm 2011 [23]	RCT; Parallel	Initial: 32 patients; 43 implants Final: 30 patients; 41 implants N/n: T = 15/22, C = 15/19 non-smoker	PD ≥ 4 mm, BOP and suppuration and radiographic (loss of supporting bone≤30% compared with the situation after implant placement;	Air-abrasive device was used with amino acid glycine powder. 5 s on each site.	mechanical debridement with chlorhexidine digluconate solution	BOP, PI, PD, CAL and MR	3; 6 months
John 2015 [18]	RCT; Parallel	Initial: 32 patients; Final: 25 patients; 36 implants N/n: T = 12/18, C = 13/18 non-smoker	PD ≥ 4 mm, BOP, loss of supporting bone ≤30% compared to the situation after implant placement	Air-abrasive device was employed with amino acid glycine powder. 5 s on each site.	mechanical debridement with chlorhexidine digluconate solution and submucosal application of chlorhexidine gel	BOP, PI, PD, CAL and MR	12 months
Merli 2020 [33]	RCT; Parallel	Initial: 32 patients; Final: 29 patients; 29 implants N/n: T = 13/13, C=16/16	PD: 5-8 mm BOP or suppuration, and radiographic bone loss, Radiographic infra-osseous component of the defect ≤ 5 mm Radiographic suprabony component of the defect ≤ 4 mm	Nonsurgical debridement and air-polishing with glycine powder	Nonsurgical debridement alone	BOP, PD, CAL, MBL and MR	6 months
Hentenaar 2021 [21]	RCT; Parallel	Initial: 80 patients; 139 implants Final: 76 patients 133 implant N/n: T = 38/63, C = 38/70	PD ≥ 5 mm, MBL ≥2 mm as compared to bone level at implant placement, bleeding and/or suppuration on probing	mouth rinse with chlorhexidine and cetylpyridinium chloride and air polisher using erythritol-based powder	mouth rinse with chlorhexidine and cetylpyridinium chloride and ultrasonic scaler	BOP, SOP, PD, MBL and PS	3 months
Selimović 2023 [32]	RCT; Parallel	Initial: 43 patients; 62 implants Final: 40 patients 57 implants N/n: T = 20/26, C = 20/31	PD ≥ 4 mm, CBL ≥ 2 mm , bleeding and/or suppuration on probing	mouthwash and ultra-sonic device with a titanium tip and low abrasive erythritol powder air-polishing; repeated treatments at 3, 6, 9, and 12 months.	mouthwash and ultrasonic device with a titanium tip and polishing paste delivered with a rotating rubber cup; repeated treatments at 3, 6, 9, and 12 months.	BOP, SOP, PD, CBL and PS	6; 12 months
Peri-implant mucositis							
Ji 2013[31]	RCT; Parallel	24 patients; 33 implants; N/n: T = 12/17, C = 12/16 non-smoker	PD ≥ 4 mm and BOP positive; no detectable loss of supporting bone as compared with periapical radio- graphs immediately after restoration	mechanical debridement and treatment of glycine powder air-polishing, 5 s on each site.	mechanical debridement	PD, BOP, Modified PI	1 week; 1;3 Months
Riben 2015 [20]	RCT; Parallel	Initial: 37 patients ; 37 implants Final: 36 patients; 36 implants; N/n: T = 18/18, C = 18/18 current smokers: 5 patients	PD ≥ 4 mm; BOP with or without suppuration; bone loss ≤ 2 mm	glycine powder air-polishing; 5 s on each site , repeated treatment at 3 and 6 months.	ultrasonic debridement with a hightech plastic material coated tip, repeated treatment at 3 and 6 months	PD, BOP, PS	1, 3; 6; 9; 12 Months
Lupi 2016 [19]	RCT; Parallel	46 patients; 88 implants; N/n: T = 24/51, C = 22/37 non-smoker	Healthy implants or implants with signs of mild inflammation of the peri-implant mucosa were included.	air-abrasive device with glycine powder, 5 s on each site.	mechanical debridement with chlorhexidine digluconate solution and submucosal application of chlorhexidine gel	PD, PI, BOP, bleeding score and CAL	3; 6 Months
Ghazal 2017 [29]	RCT; Parallel	Initial: 20 patients Final: 18 patients; 25 implants N/n: T = 9/15, C = 9/10	The peri-implant tissues had to be either healthy or have 1–6 bleeding sites without evidence of pathologic bone loss; bone loss ≤ 2 mm	Air-Flow utilizes a low abrasive air-polishing glycine powder mixture and water, 5 s on each site, repeated treatments at 3, 6, 9, and 12 months.	debridement with the use of titanium curettes, repeated treatments at 3, 6, 9, and 12 months.	PD, BOP, PS	3; 6; 12 Months

(*continued on next page*)

Table 1 (*continued*)

Study	Type	Population	Case definition	Test group	Control group	outcomes	Follow-up
Clementini 2023 [30]	RCT; Parallel	75 patients; 179 implants N/n: T = 25/58, C = 25/62	bleeding and/or suppuration on probing without a progressive radiographic bone loss (<2 mm) or bone level < 3 mm	mechanical instrumentation using titanium curettes and erythritol powder air-polishing, 5 s on each site	mechanical instrumentation using titanium curettes	PD, BOP, PI	1; 3; 6 Months

RCT: randomized clinical trial; N/n: number of patients/number of implants T: test group C: control group; PD: probing depth; BOP: bleeding on probing; PI: plaque index; CAL: clinical attachment level; MR: mucosal recession SOP： suppuration on probing; MBL: marginal bone level; PS: plaque score; CBL: crestal bone level.

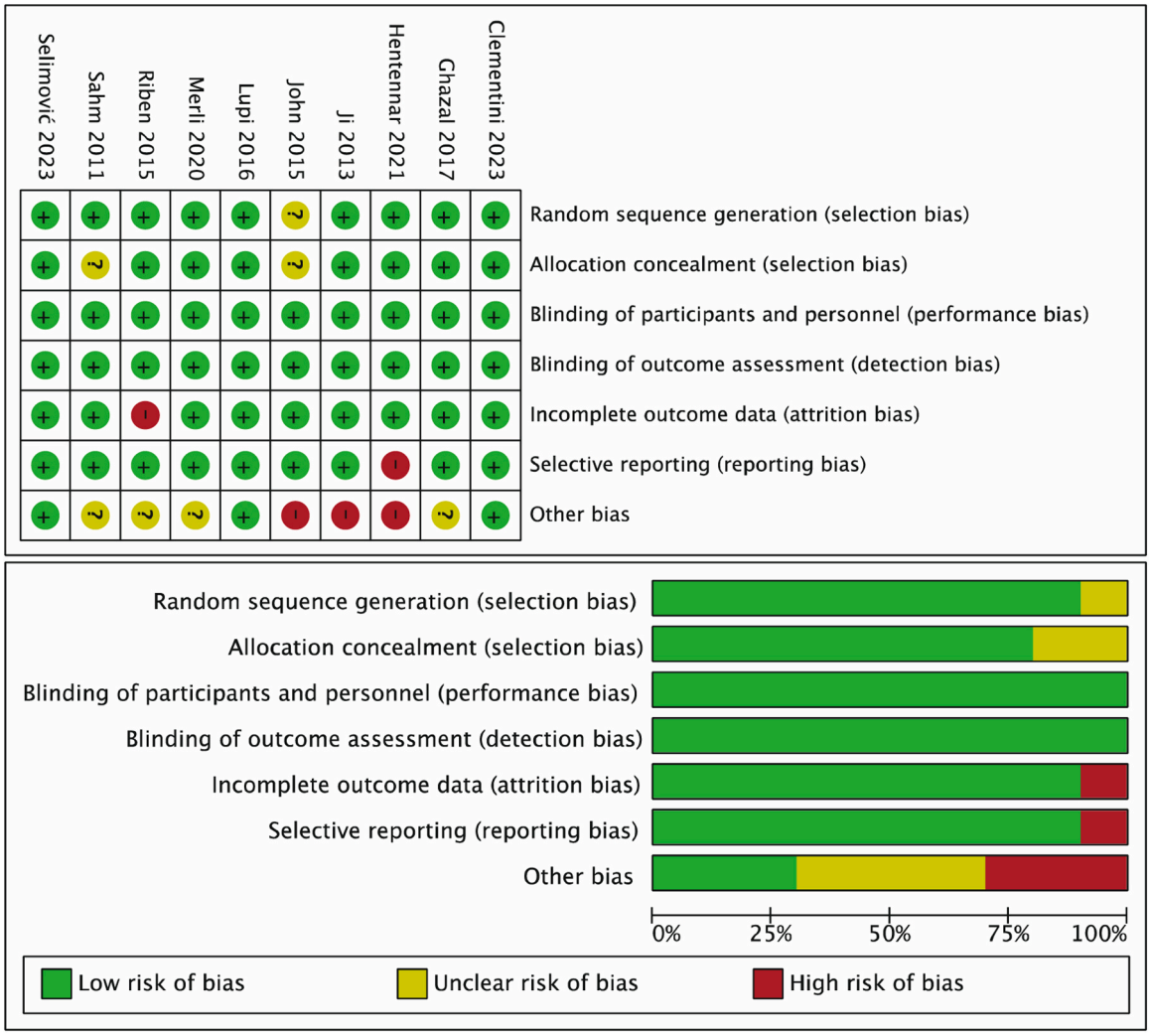

Fig. 2. Quality assessment of the selected studies (the Revised Cochrane risk of bias tool for randomized trials (rob2)). Green represents a low risk of bias, yellow represents some concerns and red represents a high risk of bias.

3.6. Publication bias

In this systematic review and meta-analysis, we found no evidence of publication bias by the result of the Egger's tests ($p > 0.05$), except for PI/PS changes in the long term for peri-implant mucositis ($P < 0.05$) (Fig. S2).

3.7. Sensitivity analysis

Sensitivity analysis (leave-one-out method) revealed no significant change in the pooled estimation when excluding any individual study (Fig. S3).

4. Discussion

4.1. Summary of findings

Analyzing the data from the included studies allowed us to deduce that, air-polishing exhibited a comparatively limited therapeutic efficacy when set against mechanical debridement.

Peri-implant diseases, occurring after the effective integration of an endosseous implant, arise due to an imbalance between bacterial challenges and the host response. These conditions may impact solely the peri-implant mucosa, leading to peri-implant mucositis, or extend to involve the underlying supporting bone, resulting in peri-implantitis

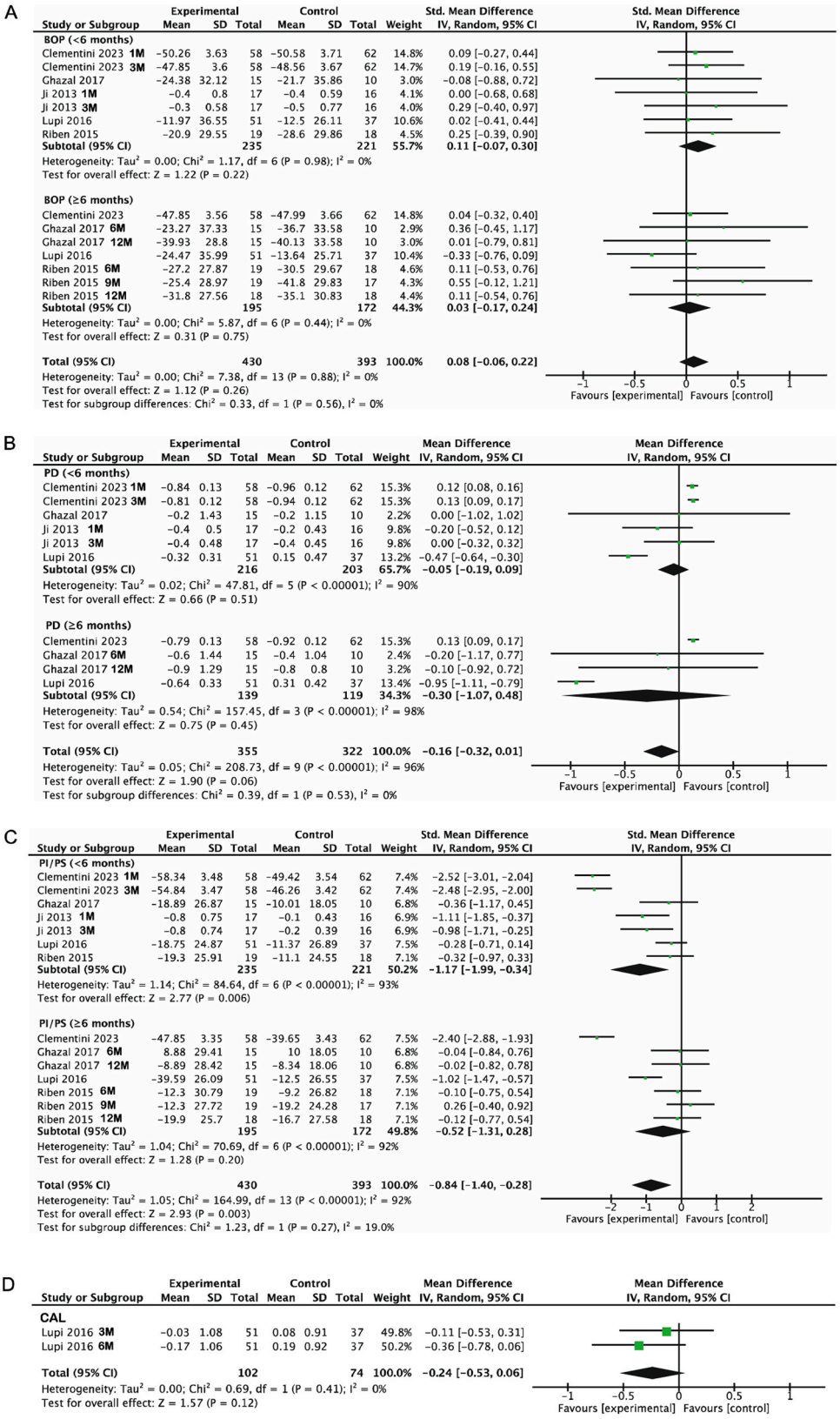

Fig. 3. Forest plot of clinical changes at peri-implant mucositis. (A) BOP; (B) PD; (C) PI/PS; (D) CAL.

[34]. Since the causes of periodontitis and peri-implant infections are highly similar, it is evident that all therapeutic strategies should primarily focus on anti-infective measures through biofilm removal. In treating periodontitis, this involves providing detailed instructions to enhance oral hygiene practices alongside a comprehensive mechanical debridement of contaminated root surfaces. However, when addressing peri-implant infections, special consideration must be given to protecting the implant surface during procedures, given the unique

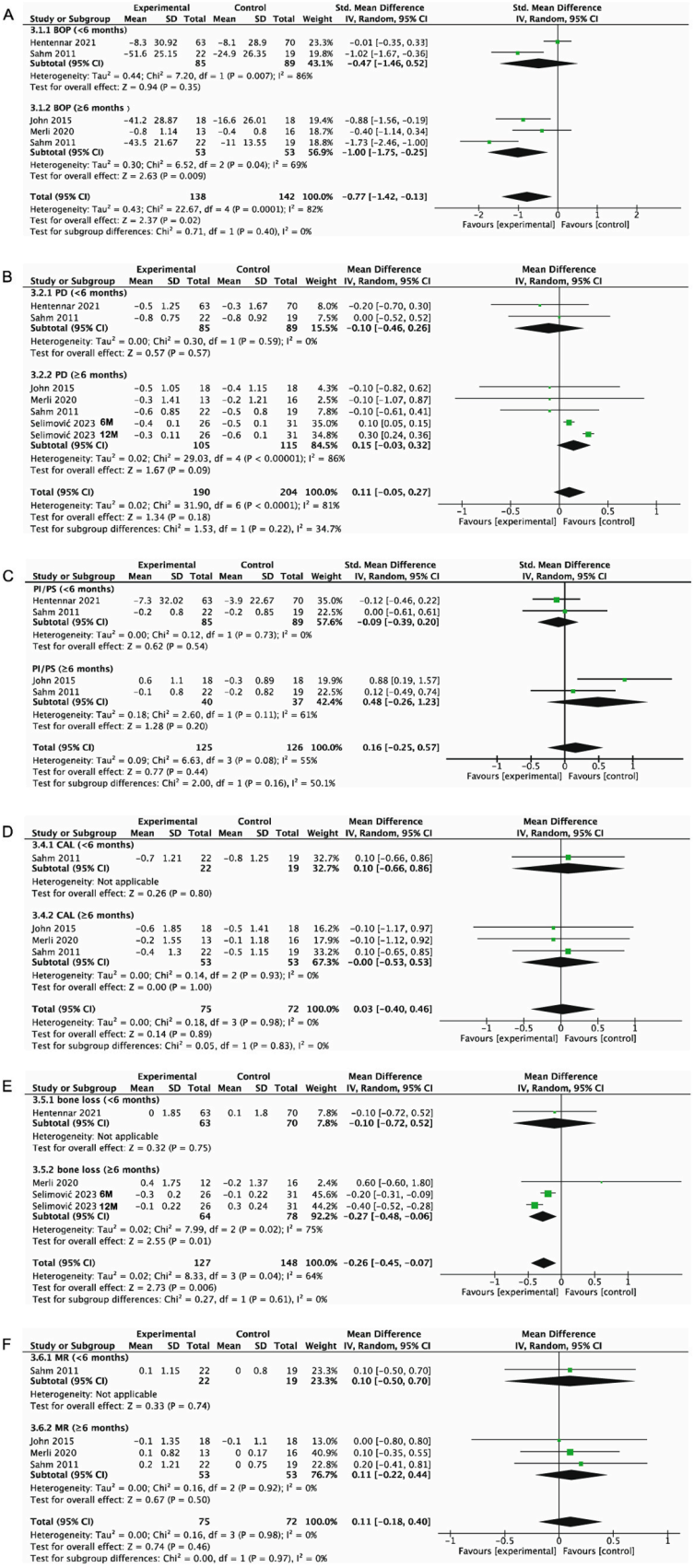

Fig. 4. Forest plot of clinical changes at peri-implantitis. (A) BOP; (B) PD; (C) PI/PS; (D) CAL; (E) bone loss; (F) MR.

Table 2
Quantitative results of included studies.

Study	Follow up	BOP		PD (mm)		PI/PS		CAL (mm) MBL* (mm) CBL# (mm)		MR (mm)	
		Intervention	Control	Intervention	Control	Intervention	Control	Intervention	Control	Intervention	Control
Sahm 2011 [23]	Baseline	94.6 ± 15.8%	95.3 ± 9.6%	3.8 ± 0.8	4.0 ± 0.8	1.2 ± 0.8	1.0 ± 0.9	4.8 ± 1.3	4.8 ± 1.3	1.0 ± 1.1	0.7 ± 0.8
	3 months	43.0 ± 29.0%	70.4 ± 29.8%	3.0 ± 0.7	3.2 ± 1.0	1.0 ± 0.8	0.8 ± 0.8	4.1 ± 1.1	4.0 ± 1.2	1.1 ± 1.2	0.7 ± 0.8
	6 months	51.1 ± 24.7%	84.3 ± 15.5%	3.2 ± 0.9	3.5 ± 0.8	1.1 ± 0.8	0.8 ± 0.7	4.4 ± 1.3	4.3 ± 0.9	1.2 ± 1.3	0.7 ± 0.7
Ji 2013 [31]	Baseline	1.4 ± 0.57	1.5 ± 0.65	3.6 ± 0.47	3.5 ± 0.50	1.2 ± 0.85	0.6 ± 0.40	-	-	-	-
	1 months	1.0 ± 0.91	1.1 ± 0.50	3.2 ± 0.52	3.3 ± 0.26	0.4 ± 0.57	0.5 ± 0.46	-	-	-	-
	3 months	1.1 ± 0.58	1.0 ± 0.85	3.2 ± 0.48	3.1 ± 0.38	0.4 ± 0.32	0.4 ± 0.38	-	-	-	-
Riben 2015 [20]	Baseline	43.9 ± 31.82%	53.7 ± 33.52%	-	-	25.5 ± 29.64%	24.1 ± 28.00%	-	-	-	-
	3 months	23 ± 26.59%	25.1 ± 23.76%	-	-	6.2 ± 11.33%	13.0 ± 17.82%	-	-	-	-
	6 months	16.7 ± 20.05%	23.2 ± 22.91%	-	-	13.2 ± 31.82%	14.9 ± 25.46%	-	-	-	-
	9 months	18.5 ± 24.85%	11.9 ± 9.90%	-	-	13.2 ± 25.28%	4.9 ± 12.78%	-	-	-	-
	12 months	12.1 ± 16.12%	18.6 ± 27.15%	-	-	5.6 ± 16.12%	7.4 ± 27.15%	-	-	-	-
John 2015 [18]	Baseline	99.0 ± 4.1%	94.7 ± 13.7%	3.7 ± 1.0	3.9 ± 1.1	1.2 ± 1.1	1.2 ± 1.0	5.2 ± 1.9	5.0 ± 1.5	1.5 ± 1.4	1.0 ± 1.1
	12 months	57.8 ± 30.7%	78.1 ± 30.0%	3.2 ± 1.1	3.5 ± 1.2	1.8 ± 1.1	0.9 ± 0.7	4.6 ± 1.8	4.5 ± 1.3	1.4 ± 1.3	0.9 ± 1.1
Lupi 2016 [19]	Baseline	45.3 ± 39.47%	84.09 ± 25.05%	2.51 ± 0.24	2.39 ± 0.46	85.42 ± 23.22%	85.23 ± 25.19%	1.06 ± 1.07	0.55 ± 0.87	-	-
	3 months	33.33 ± 32.69%	71.59 ± 27.05%	2.19 ± 0.35	2.54 ± 0.48	66.67 ± 26.24%	73.86 ± 28.32%	1.03 ± 1.09	0.63 ± 0.94	-	-
	6 months	20.83 ± 30.99%	70.45 ± 26.32%	1.87 ± 0.38	2.70 ± 0.37	45.83 ± 28.23%	72.73 ± 27.72%	0.89 ± 1.04	0.74 ± 0.96	-	-
Ghazal 2017 29]	Baseline	57.71 ± 30.75%	50.03 ± 38.51%	4.3 ± 1.49	5.0 ± 0.81	35.56 ± 28.80%	16.67 ± 20.79%	-	-	-	-
	3 months	33.33 ± 33.33%	28.33 ± 32.44%	4.1 ± 1.35	4.8 ± 1.31	16.67 ± 24.40%	6.66 ± 11.65%	-	-	-	-
	6 months	34.44 ± 41.53%	13.33 ± 15.31%	3.7 ± 1.38	4.6 ± 1.17	44.44 ± 29.99%	26.67 ± 11.65%	-	-	-	-
	12 months	17.78 ± 26.33%	9.99 ± 16.10%	3.4 ± 0.83	4.2 ± 0.78	26.67 ± 28.03%	8.33 ± 11.79%	-	-	-	-
Merli 2020 [33]	Baseline	3.6 ± 0.8	3.3 ± 0.8	5.1 ± 1.5	4.4 ± 1.1	-	-	5.4 ± 1.6 3.6 ± 1.7 *	4.4 ± 1.0 3.3 ± 1.2 *	0.2 ± 0.9	0.1 ± 0.1
	6 months	2.8 ± 1.3	2.9 ± 0.8	4.8 ± 1.3	4.2 ± 1.3	-	-	5.2 ± 1.5 4.0 ± 1.8 *	4.3 ± 1.3 3.1 ± 1.5 *	0.3 ± 0.7	0.1 ± 0.2
Hentenaar 2021 [21]	Baseline	58.1 ± 30.3%	56.2 ± 28.8%	4.8 ± 1.2	5.0 ± 1.5	23.2 ± 33.2%	16.0 ± 22.1%	4.0 ± 1.9 *	3.9 ± 1.8 *		
	3 months	49.8 ± 31.5%	48.1 ± 29.0%	4.3 ± 1.3	4.7 ± 1.8	15.9 ± 30.7%	12.3 ± 23.2%	4.0 ± 1.8 *	4.0 ± 1.8 *		
Clementini 2023 [30]	Baseline	85.48 ± 2.35%	88.22 ± 2.21%	3.96 ± 0.14	4.23 ± 0.14	84.95 ± 2.73%	87.93 ± 2.81%	-	-	-	-
	1 months	35.22 ± 4.18%	37.64 ± 4.28%	3.12 ± 0.11	3.27 ± 0.10	26.61 ± 3.92%	38.51 ± 3.98%	-	-	-	-
	3 months	37.63 ± 4.14%	39.66 ± 4.24%	3.15 ± 0.10	3.29 ± 0.10	30.11 ± 3.91%	41.67 ± 3.81%	-	-	-	-
	6 months	37.63 ± 4.09%	40.23 ± 4.22%	3.17 ± 0.11	3.31 ± 0.10	37.10 ± 3.74%	48.28 ± 3.82%	-	-	-	-
Selimović 2023 [32]	Baseline	-	-	4.5 ± 0.10	4.4 ± 0.10	-	-	3.6 ± 0.22#	3.1 ± 0.20#	-	-
	6 months	-	-	4.1 ± 0.10	3.9 ± 0.09	-	-	3.3 ± 0.18#	3.0 ± 0.23#	-	-
	12 months	-	-	4.2 ± 0.11	3.8 ± 0.09	-	-	3.5 ± 0.21#	3.4 ± 0.27#	-	-

characteristics of implant materials and their surface features, as well as the integration with the surrounding bone. Considering the latest data synthesis, various alternative approaches for biofilm removal, such as air-polishing and chitosan brushes, as well as interventions like a laser, photodynamic therapy, local antiseptic therapy, probiotics, and mouth rinses have been explored [10,12,23,35–37].

The findings from this systematic review and meta-analysis reveal that the air-polishing group exhibited a notable decrease in the PI/PS for peri-implant mucositis in the short term (<6 months). Regarding the long-term clinical outcomes, no significant distinctions were identified between the experimental and placebo groups. In the context of peri-implantitis, air-polishing therapy appears to be advantageous in diminishing both BOP and bone loss when compared to the control group over the long term (≥6 months). However, no significant variances were observed in the short term (<6 months). In the subgroup analysis based on various polishing powders, the findings revealed a significant superiority of glycine over erythritol in reducing BOP. Furthermore, our investigation revealed no indications of publication bias based on the results of Egger's tests, except in the case of PI/PS changes in the long term concerning peri-implant mucositis. Sensitivity analysis using the leave-one-out method demonstrated no substantial alterations in the overall estimation when excluding any individual study. Despite acknowledging the potential for publication bias, it is highlighted that the data trends remain consistent across these studies. Additionally, emphasis is placed on the reliability of the included studies and the use of standardized assessment methods, contributing to increased confidence in the reported findings.

4.2. Agreements and disagreements with other studies

Two recent meta-analyses have explored the effectiveness of air-polishing on peri-implant diseases [7,22]. Boeira *et al.* observed a modest impact of glycine air-polishing on PD in peri-implant mucositis compared to manual curettage. However, the available evidence is inadequate to endorse the use of either glycine air-polishing or curette debridement for reducing indicators of peri-implant diseases [22]. Schwarz *et al.* concluded that glycine powder air-polishing exhibited similar effectiveness in control treatments at mucositis sites. Nonetheless, it showed potential for improving the efficacy of non-surgical peri-implantitis treatment in comparison to the investigated control measures [7]. Concerning BOP in this meta-analysis, distinctions were observed among treatments for peri-implantitis but not for peri-implant mucositis. These findings may be attributed to the possibility that peri-implantitis involves more severe tissue damage, resulting in a higher baseline level of BOP. In studies by Sahm and John *et al.* [18,23], the baseline average level of BOP was around 95%. In contrast, peri-implant mucositis may entail less tissue damage, leading to a lower baseline level of BOP, and thus, its impact may not be as pronounced. This hypothesis aligns with the research outcomes reported by Clementini *et al.* [30]. No significant difference in PD was identified between treatments for both peri-implantitis and peri-implant mucositis. This is in contrast to the findings reported by Boeira *et al.* [22] The disparity in findings may be attributed to the confounding factors mentioned by Selimović *et al.* [32] and the different grouping methodologies employed. One study grouped data based on each time node, while the other categorized them into a group spanning from 6 months to 12 months. Air-polishing demonstrated a noteworthy decrease in PI/PS compared to mechanical or ultrasonic debridement for treating short-term peri-implant mucositis. Nevertheless, this reduction was less apparent in patients undergoing long-term follow-up after the treatment of peri-implant mucositis or in those with follow-up for peri-implantitis. The efficacy of air-polishing in eliminating sub-gingival calculus and plaque may be limited by its pressure and abrasive potential. This conclusion corroborated with the outcomes of the research conducted by Merli *et al.* and Persson *et al.*[33,38], both of which indicated no substantial variation in microbiological outcomes across the different treatment methods utilized. In terms of bone loss, our study indicates a substantial decrease with the use of air-polishing techniques when applied over an extended period of six months or longer. This demonstrates a marked preference for air-polishing as a treatment method. Additionally, three studies conducted repeated treatments at follow-up [20,29,32]. In contrast, other studies exclusively implemented interventions at baseline. However, the results of sensitivity analysis using the leave-one-out method showed no significant alterations in the overall estimation when excluding any individual study. This suggests that the timing difference in implementing intervention may have minimal impact on the results.

As mentioned above, peri-implant diseases result from plaque retention around the implant, accompanied by an imbalance between bacterial challenges and the host response. As for non-surgical lesion treatment, it is recommended that the "absence of BOP signifies the resolution of peri-implant mucositis, while the absence of deep PD, BOP, and suppuration indicates the resolution of peri-implantitis" as treatment endpoints [39]. Based on the above criteria and the data from the studies we included, it can be inferred that air-polishing has limited therapeutic efficacy over mechanical debridement in certain clinical outcomes of peri-implant diseases.

Furthermore, technological advancements have led to an increasing variety of polishing powders. In recent years, accumulating evidence supports the anti-inflammatory, immunomodulatory, and cytoprotective effects of glycine [40]. Hashino *et al.* demonstrated that erythritol inhibited dual-species biofilm development through various pathways. These include the suppression of growth, leading to DNA and RNA depletion, reduced extracellular matrix production, and modifications in dipeptide acquisition and amino acid metabolism [41]. Drago *et al.* reported that air-polishing with erythritol-chlorhexidine could be a practical alternative to the conventional glycine treatment for biofilm removal [42]. Nevertheless, our analysis indicated that glycine was more effective in reducing BOP compared to erythritol. This difference may be attributed to the use of chlorhexidine in addition to the polishing powder in Drago *et al.*'s study. To examine the effects of various types of powders, more relevant experiments are required for confirmation.

4.3. Limitation

In this systematic review and meta-analysis, some limitations arise from the inevitable differences among included studies. Firstly, as smoking has been proven to be a risk factor for peri-implantitis, only four studies excluded smoker patients, while the other five studies included both smokers and nonsmokers. It may potentially jeopardize the results of pooled estimates. Secondly, heterogeneity among the included studies was noted concerning the control groups, encompassing manual curettage, ultrasonic scalers, and the supplementary use of chlorhexidine (CHX). Thirdly, variations in the diagnostic criteria, the severity of patients' conditions, the soft tissue phenotype (e.g., the thickness of keratinized mucosa) and the potential confounding factor (e.g., clinical operation, examination) can all potentially influence the outcomes. Lastly, the quality and significance of the conclusions in this systematic review may be slightly affected by the presence of limited data, substantial heterogeneity, and the inclusion of small-scale studies.

5. Conclusion

In nonsurgical peri-implant disease management, air-polishing moderately reduced short-term PI/PS for peri-implant mucositis and showed a similar decrease in long-term BOP and bone loss for peri-implantitis compared to the control group. However, it must be acknowledged that, based on the data extracted from the included studies, there are inherent limitations to the overall efficacy of air-polishing. Moreover, the challenge of drawing a conclusive determination on the efficacy of air-polishing in the treatment of peri-implant disease persists, given the complexity and variability of the condition.

In light of these results, future research endeavors should aim to incorporate longer-term patient follow-up and conduct high-quality, multi-center, large-sample RCTs.

Ethics approval

Not applicable.

Contributors

NH and YL performed literature searching, data collection and analyses, drafted the manuscript. HC, WL, CW and YO provided help in the literature searching and figure revises. Masahiro Likubo critically reviewed the manuscript. JC applied for funding, designed the experiment and critically reviewed the manuscript. All authors agree to be accountable for the study.

Conflict of interest

The authors declare no potential conflicts of interest.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

Patient consent for publication

Not applicable.

Funding

This work was supported by research funding from the National Natural Science Foundation of China (82371008).

Data Availability

Data are available upon reasonable request. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jdsr.2024.05.003.

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