Ethan Ng

The efficacy of air polishing devices in supportive periodontal therapy: A systematic review and meta-analysis

Ethan Ng, BSc (Hons), DMD[1]/Roy Byun, B Med Sc (Hons), PhD, MHP[2]/Axel Spahr, Dr Med Dent Habil[3]/Tihana Divnic-Resnik, BDS, MSc, PhD[4]

Objective: This systematic review analyzes existing literature on the clinical efficacy of air polishing devices (APDs), discussing the evidence-based data available for justifying their use as an alternative to conventional periodontal debridement in supportive periodontal therapy. The main objective of the review was to assess whether APD was as equally efficient or superior in obtaining successful treatment outcomes when compared with conventional methods. **Data Sources:** Following PRISMA guidelines, a systematic literature search of articles in English, up to December 2016, was conducted using PubMed, Cochrane, and Medline. Relevant articles were selected based on specific criteria. Seven studies were selected for the final assessment. One more study was added after a manual search of the literature. Due to considerable heterogeneity in study designs and outcome variables measured, only clinical parameters (probing depth, bleeding on probing, and clinical attachment level) were selected for meta-analysis. **Conclusion:** The studies selected for this systematic review provide some evidence that APDs as monotherapy could be an alternative to conventional debridement of single- and multi-rooted teeth with no furcation involvement, during supportive periodontal therapy. Comparing clinical and microbiologic outcomes, APDs seem to be as effective as conventional treatments. The primary advantage for the use of APDs in supportive periodontal therapy seems to be their ability to efficiently remove biofilm, without causing damage to the periodontal soft tissues or tooth and root structure. There may also be an advantage regarding patient comfort and time consumed.
(doi: 10.3290/j.qi.a40341)

Key words: dental air abrasion, dental/instrumentation, erythritol, glycine, periodontal pocket/therapy, sodium bicarbonate

[1]Graduate Student, Faculty of Dentistry, University of Sydney, Sydney, NSW, Australia.

[2]Senior Policy Analyst – Oral Health Services, Centre for Oral Health Strategy, Sydney, NSW, Australia.

[3]Associate Professor and Head, Department of Periodontology, Faculty of Dentistry, University of Sydney, Sydney, NSW, Australia.

[4]Lecturer, Department of Periodontology, Faculty of Dentistry, University of Sydney, Sydney, NSW, Australia.

Correspondence: Dr Ethan Ng, 2 Chalmers Street, The University of Sydney, Sydney, NSW 2006, Australia. Email: etng1324@gmail.com

The stability of periodontal conditions depends on the balance between bacterial challenge and host response.[1] To maintain periodontal stability, periodontal treatment needs to be followed by long-term supportive periodontal therapy (SPT),[2] ie, periodontal maintenance. The aim of SPT is to prevent or reduce the progression of periodontal disease and tooth loss in patients who have successfully

Table 1 Commercially available powders (Electro Medical Systems) and indications for use

Commercial powder	Powder particle	Average particle size	Application	Handpieces	Indication for use			
					Removal of heavy discolorations	Removal of medium-light discolorations	Tooth polishing	Removal of biofilm from periodontal pockets 4–10 mm
Air-flow powder classic	Sodium bicarbonate	~65 µm	Supragingival	Air-flow	✓			
Air-flow powder classic comfort	Sodium bicarbonate comfort	~40 µm	Supragingival	Air-flow	✓			
Air-flow powder soft	Glycine (GPAP)	~65 µm	Supragingival	Air-flow		✓	✓	
Air-flow powder plus	Erythritol (EPAP) (contains 0.3% CHX)	~14 µm	Subgingival	Air-flow or air-flow plus		✓	✓	✓
Air-flow powder perio	Glycine	~25 µm	Supra- or subgingival	Air-flow perio				✓

CHX, chlorhexidine; EPAP, erythritol powder air polishing; GPAP, glycine powder air polishing.

completed initial periodontal therapy.[3] Because periodontal pockets are recolonized rapidly,[4] regular recall intervals are recommended with a frequency depending on disease severity, the quality of hygiene, and various systemic risk factors.[3] Besides maintaining and reestablishing sufficient oral hygiene, regular removal of newly formed supra- and subgingival biofilm and calculus is a core component of SPT.[5] This has traditionally been accomplished by mechanical nonsurgical debridement with sonic/ultrasonic devices and hand instruments.

Mechanical nonsurgical periodontal debridement has been shown to predictably reduce inflammation and probing pocket depths (PPDs), as well as facilitate clinical attachment gain.[6] The most common form of nonsurgical therapy can be termed "conventional treatment," and is commonly known as scaling and root planing (SRP). This approach mainly consists of hand scaling with scalers or curettes, as well as the use of powered instruments such as sonics and ultrasonics. Although effective during SPT, there are some limitations or side effects due to conventional treatment. These include iatrogenic damage to hard and soft tissues, as well as the need for local anesthetics to alleviate the discomfort of the procedure. Inevitably, removal of cementum from the root surface and exposure of root dentin following regular SPT will expose dentinal tubules and consequently induce tooth sensitivity.[7-10]

A systematic review conducted in 2012 estimated that the prevalence of tooth sensitivity one day after periodontal therapy was between 62.5% and 90%, subsequently decreasing to about 50% after one week.[11] Regular SPT following periodontal treatment may further increase tooth hypersensitivity and ultimately affect patient compliance. For the dentist, conventional SPT can be labor- and time-intensive. Anatomical variations such as grooves, concavities, and cervical enamel projections can result in stagnant ecologic niches for bacteria,[12] representing an area that is more challenging to debride efficiently. The degree of pocket depth and operator experience also has an impact on the quality of debridement.[13,14] Particularly for regularly repeated procedures such as SPT, it is important to be efficient and cause minimal or no damage to the tissues or discomfort to the patient.

Recent improvements in air polishing devices (APDs) provide an alternative form of biofilm removal that may be useful, particularly for SPT. The underlying principle behind APDs is to produce a stream of small particles, mixed with pressurized air and a jet of water, forming an abrasive "slurry" that is capable of removing

doi: 10.3290/j.qi.a40341

biofilm as well as stains.[15] Therefore, the indication for use of APDs has expanded from supragingival, utilizing highly abrasive sodium bicarbonate powders, to subgingival applications. With the development of new degradable and less abrasive powders in combination with newly designed subgingival application devices, access to and cleaning of deeper pockets and interdental areas is now achievable. Two newly introduced powders, glycine and erythritol, have been tested in clinical studies, and have been safely used in subgingival areas. A summary of commercially available powders together with their clinical application and corresponding handpieces is listed in Table 1. Subgingival powders used in combination with a standard handpiece, commonly used for supragingival plaque and stain removal, can reach a subgingival penetration depth of up to 4 mm when directed into the orifice of a periodontal pocket.[16] More recently, a new subgingival nozzle has been developed, allowing treatment of deeper periodontal pockets of > 5 mm.[17] The nozzle has two outlets located approximately 2 mm above the tip of the nozzle, allowing the air-powder mixture to exit horizontally towards the root surface and pocket epithelium. The third outlet, located at the tip of the nozzle, releases the water spray only and provides irrigation and removal of loose biofilm and debris.[18] The nozzle is flexible, and made of thermoplastic elastomer to facilitate easier penetration into the pocket and adjustment to the root surface. It reduces the jet-spray pressure to 1 bar, allowing a gentle clean and reduction of potential adverse effects such as tissue irritation and air emphysema.

This systematic review and meta-analysis addresses the question "Is there sufficient evidence to justify the use of APDs in combination with low abrasive and degradable powders as an alternative to conventional SPT using hand or power instruments?"

DATA SOURCES

Focused PICO question

The PICO (Population, Intervention, Comparison, Outcomes) method was used to formulate the research question, where the population consisted of patients undergoing SPT. The intervention was the usage of APDs; the comparator was conventional hand scaling with curettes or hand scalers or ultrasonic instruments or a combination of both. The primary outcomes assessed included probing depth (PPD), bleeding on probing (BOP), and clinical attachment level (CAL). Secondary outcomes included microbiologic changes and patient perception of pain/discomfort during the treatment (visual analog scale [VAS]). Based on the four components of PICO, the final research question was composed: "For patients in the SPT phase, is the use of APD equal or superior to conventional debridement with hand scaling and power-driven instruments, when comparing clinical and microbiologic parameters as well as patient tolerance?"

Protocols and search strategy

After establishing the research question, the review was conducted by following the Preferred Reporting Items for Systematic review (PRISMA) guidelines. An online search of the following electronic databases was done and relevant published articles relating to the use of APDs in SPT were selected (Fig 1): The Cochrane Database of Systematic Reviews (CDSR), American College of Physicians (ACP) Journal Club, Database of Abstracts of Reviews of Effects (DARE), Current Cancer Therapy Reviews (CCTR), Cochrane Methodology Register (CMR), Health Technology Assessment Database (HTA), NHS Economic Evaluation Database (EED), Embase, and Ovid Medline(R). The following key words were used in the search strategy:

- Intervention: [(periodontal treatment or periodontal therapy) OR (perio-treatment or perio-therapy)] AND (maintenance or supportive therapy) AND (air polishing OR air abrasive*) AND [(universal curette* or Gracey curette* OR ultrasonic scaling or debridement OR hand scal*)] AND [periodontal diseases or periodontitis or aggressive periodontitis or chronic periodontitis or periodontal abscess or periodontal pocket] AND [glycine powder or erythritol powder]
- Outcome: [(probing depth or pocket depth) OR bleeding on probing OR (clinical attachment loss or level) OR gingival recession].

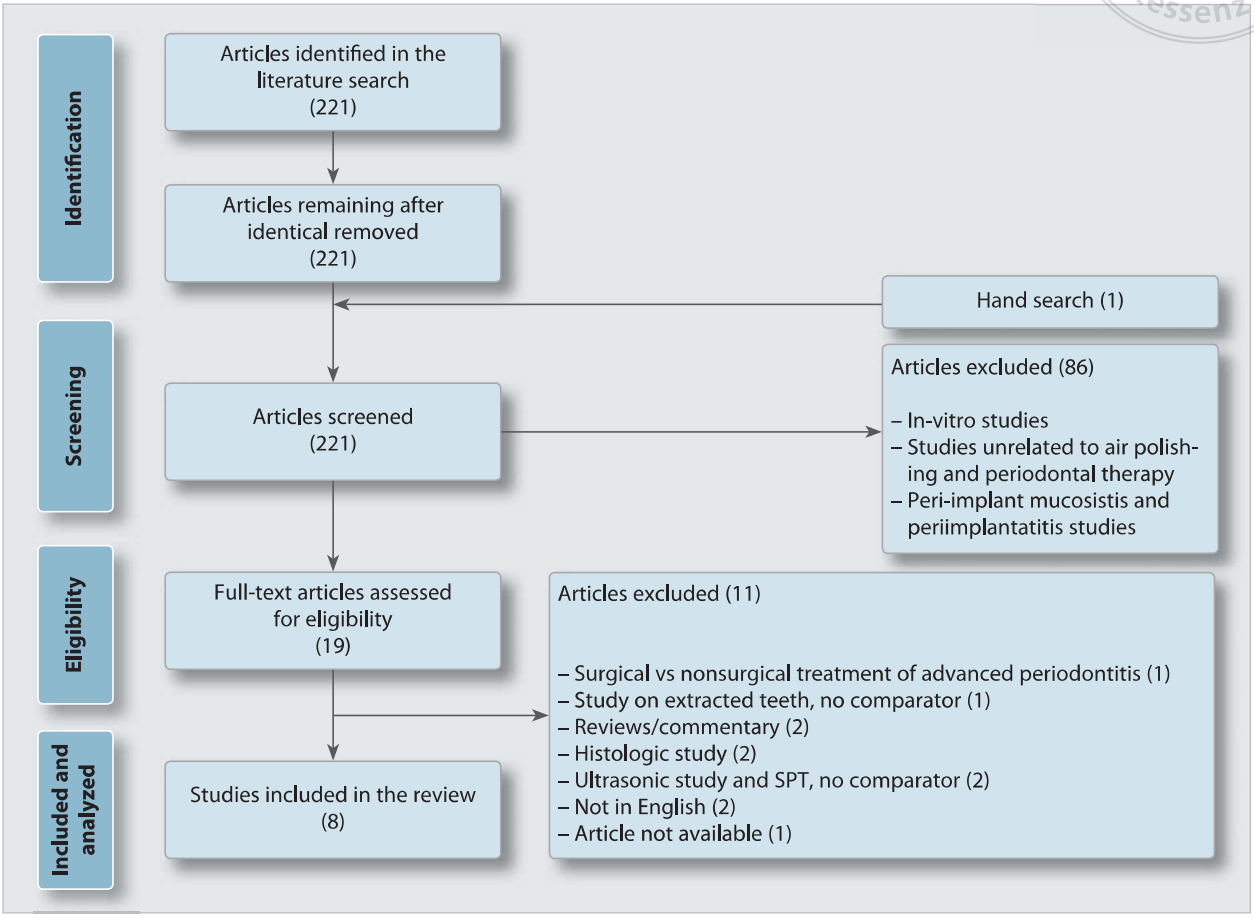

Fig 1 Flowchart showing the study selection process (SPT, supportive periodontal therapy).

The inclusion criteria were:

- original clinical studies in humans published from 2000 to current date (last search done in December 2016)
- randomized controlled clinical trials (RCTs)
- controlled clinical trials
- adult subjects (> 19 years of age)
- subjects in good systemic health
- intervention with APDs
- evaluation parameters: PPD, BOP, CAL, microbiologic parameters, patients' pain/discomfort perception.

Resources selection

The articles were screened by title and abstract by two independent reviewers (EN and TDR).

The first round of exclusions consisted of studies relating to in-vitro studies, studies unrelated to air polishing and periodontal therapy, followed by studies related to the treatment of peri-implant mucositis or peri-implantitis. Next, full text articles were downloaded and assessed for eligibility according to the inclusion criteria listed above. The second round of exclusions included studies on initial periodontal therapy, histologic studies, studies not in English, and reviews/commentaries. At the same time, a manual search of journals of relevance to the review topic was performed as well as a manual search of reference lists of included papers. Finally, only short- or long-term trials as agreed by both reviewers (EN and TDR), comparing the use of APD to hand scaling/ultrasonics in

doi: 10.3290/j.qi.a40341

Table 2 List of the studies that were excluded and reasons for exclusion

Excluded study	Reason for exclusion
Petersilka et al, 2008	Full text not available
Petersilka et al, 2008	In German
Zhao et al, 2015	In Chinese
Ueda et al, 2014	Study on ultrasonic devices comparing SPT intervals
Petersilka et al, 2008	Histologic outcome measures
Flemmig et al, 2007	No comparator treatment; parameters recorded after the teeth were extracted
Serino et al, 2001	Surgical vs nonsurgical treatment in the treatment of advanced periodontitis
Jenkins et al, 2000	Compares coronal scaling vs subgingival scaling during SPT
Buhler et al, 2016	Review of APD effects on oral tissues
Madan et al, 2009	Commentary on tooth polishing and relevance today
Simon et al, 2015	Histopathologic outcomes measure

SPT/periodontal maintenance in human adults were considered for review.

The database search resulted in 221 citations. After removal of duplicates due to citations in different databases, 104 titles and abstracts were screened according to the eligibility criteria (Fig 1).

A further 86 articles were excluded because they did not address the question of this systematic review. Manual search resulted in one eligible paper that was added to the database. Nineteen articles were selected for full text reading. The list of excluded studies and reasons for their exclusion is provided in Table 2. Eventually, eight studies were identified as eligible for systematic review according to the defined criteria for study design, participants, intervention, and outcomes (Table 3). Further assessment of their eligibility for meta-analysis after data extraction was undertaken.

Assessment of heterogeneity

The primary study results across selected studies were assessed for heterogeneity according to the factors provided below:

- evaluation period
- medical and periodontal status of the patients
- number of participants
- mean age of participants
- gender distribution
- test product/intervention type (APD)
- primary data collection
- use of antibiotics
- smoking
- industry funding.

Quality assessment

In order to extract quality-related data, the quality assessment of the selected studies was based upon the following aspects:

- study design
- randomization
- sources of bias
- follow-up/attrition rate
- data collection (parameters of periodontal disease, microbiologic sampling/assessment, pain/discomfort perception).

Data extraction

Data extracted from comparative studies included clinical parameters (PPD, BOP, and CAL) as primary outcomes and microbiologic parameters and pain/discomfort perception as secondary treatment outcomes. Baseline, end mean values, standard deviations (SDs), or standard

Table 3 Summary of the studies processed for analysis; all data refer to supportive periodontal therapy (SPT)

Study	Study population (patients on SPT)	Study design and evaluation period	Study aim, intervention vs comparator, methods	Outcome
Petersilka et al[21]	27 subjects (11 F, 16 M; mean age 46.4 y); smoking history not mentioned; PPD 3–5 mm; furcation sites excluded	RCT; split-mouth; no blinding; 3 mo	Aim: To assess the efficacy of subgingival plaque removal in buccal and lingual sites. Comparison: Amino acid glycine powder (no nozzle) vs curettes. Method: Microbiologic analysis of subgingival plaque-reduction in CFU assessed by anaerobic culture; patient perception assessed by VAS.	APD was found to be superior to curettes in removing subgingival plaque, with a statistically significant reduction in subgingival bacteria.
Moëne et al[17]	50 subjects (24 F, 26 M; mean age 54.9 y); 50% smokers; PPD ≥ 5 mm, range 5–9 mm; supragingival hard and soft deposits removed on the day of subgingival treatment; physical limitations or restrictions affecting normal oral hygiene procedures excluded	RCT; split-mouth two-arms parallel design; examiner masked; 7 d	Aim: To evaluate the safety, patient acceptance and short-term microbiologic effect of the newly developed system (nozzle). Comparison: Amino acid glycine powder (nozzle) vs curettes. Method: Clinical (PI) and BOP reduction. Microbiologic analysis of subgingival plaque: TBL and counts of six periodontopathogens assessed by real time PCR.	APD therapy was not superior to conventional SRP in reducing microbial counts. Conventional SRP and APD both resulted in significant reductions in BOP, but hand instrumentation was nominally better.
Wennström et al[25]	20 subjects; PPD 5–8 mm and BOP+; furcation sites excluded; smoking history not registered	Split-mouth; 2 mo	Aim: To determine clinical and microbiologic effects and perceived treatment discomfort. Comparison: Amino acid glycine powder (nozzle) vs ultrasonics. Method: Clinical: PPD reduction. Mouthrinsing with 0.1% CHX twice daily for 1 min during 14 d posttreatment. Microbiologic analysis of subgingival plaque: "checker-board" DNA-DNA hybridization technique. Patient tolerance assessed by VAS.	2-mo duration, recall at 2 weeks and d 60. Both APD and ultrasonic therapy resulted in significant reductions of periodontitis-associated bacterial species, BOP, and PPD. No significant differences between the therapies. VAS score for patients receiving APD therapy was significantly lower than for ultrasonic debridement.
Flemmig et al[18]	30 subjects (15 F, 15 M; age range 41–78 y); PPD 4–9 mm; smoking history registered; molars with class III furcation excluded	RCT; parallel group; 3 mo	Aim: To assess efficacy and safety of SubGPAP in removing bacterial biofilm in moderate–deep periodontal pockets with PPDs of 4–9 mm. Comparison: Amino acid glycine powder (nozzle) vs curettes and scalers. Method: Clinical: PPD, BOP, GR, and PI reduction. Microbiologic analysis of supra- and subgingival plaque: real-time PCR. Patient perception of discomfort assessed by VAS. Patients rinsed with 0.12% CHX after debridement, and twice daily for 2 wk.	Clinical parameters assessed at baseline and 3 mo later showed no difference between test and control groups. Total viable bacterial counts of subgingival plaque was significantly lower at test sites compared to SRP sites immediately after the treatment and at d 10. At d 90, total viable bacterial counts at investigational sites returned to baseline values at both groups. Total bacterial counts were significantly reduced after full mouth GPAP compared to SRP at d 90 ($P < .05$). Patients perceived a high level of comfort during APD and SRP, with no difference between treatments.
Hägi et al[22]	40 subjects (15 F, 25 M; mean age 54.5 y); PPD ≥ 4 mm; BOP+; smoking history registered; furcation sites excluded	RCT; parallel groups; 3 mo; single-operator blinded	Aim: To compare clinical outcomes of two subgingival treatments. Comparison: Erythritol powder (nozzle) vs curettes. Method: Clinical: BOP, PPD, and CAL reduction. Patient tolerance assessed by VAS.	No statistical difference in BOP, PPD, and CAL between test and control groups. Patient tolerance significantly better among patients receiving APD.
Müller et al[26]	50 subjects (29 F, 21 M; mean age 58.5 y); PPD > 4 mm; smoking history registered; physical limitations or restrictions affecting normal oral hygiene procedures excluded	RCT; Two-arm, within subject parallel design; 12 mo	Aim: To evaluate repeated subgingival air polishing in residual pockets with a new erythritol powder containing 0.3% CHX. Comparison: Erythritol powder (nozzle) vs ultrasonics. Method: Presence/absence of PD > 4 mm per subject. Microbiologic analysis of subgingival plaque: real-time PCR. Perception of pain/discomfort by VAS.	12-mo duration, 3-mo recall. No significant difference between APD therapy and ultrasonic debridement in terms of number of pockets and BOP.
Kargas et al[23]	25 subjects (10 F, 15 M; mean age 52.5 y); nonsmokers; PPD > 4 mm; furcation not specified as an exclusion criteria	Split-mouth; 6 mo	Aim: To assess efficacy of subgingival glycine powder on clinical and microbiologic parameters. Comparison: Amino acid glycine powder nozzle vs hand instruments and ultrasonics. Method: Clinical (PPD, RE, CAL). Microbiologic examination subgingival plaque: "checker-board" DNA-DNA hybridization technique.	Posttreatment recall at 1, 3, and 6 mo. APD group had significantly higher PPD than the SRP group. No microbiologic differences.
Hägi et al[24]	40 subjects (15 F, 25 M; mean age 54.5 y); PPD ≥ 4 mm, with no detectable calculus; smoking status registered; furcation sites excluded	RCT; parallel groups; 6 mo	Aim: To characterize the physical characteristics of EPAP and to evaluate its influence on the clinical and microbiologic parameters. Comparison: Erythritol powder (nozzle) vs curettes. Method: Physical characteristics of EPAP: assessed by scanning electron microscopy (in vitro). Clinical: PPD, BOP, CAL, plaque (%). Microbiologic analysis: PCR.	6-mo duration, 3-mo recall. EPAP and curettes resulted in significant but similar reductions of clinical parameters. The counts of perio pathogens did not change significantly during therapy either in the test or in the control group.

APD, air polishing device; BOP, bleeding on probing; CAL, clinical attachment level; CHX, chlorhexidine; EPAP, erythritol powder air polishing; F, female; GPAP, glycine powder air polishing; GR, gingival recession; M, male; PCR, polymerase chain reaction; PI, Plaque Index; PPD, probing pocket depth; RCT, randomized controlled clinical trial; RE, gingival recession; SPT, supportive periodontal therapy; SRP, scaling and root planing; TBL, total bacterial load; VAS, visual analog scale;

doi: 10.3290/j.qi.a40341

errors (SEs) were extracted by RB and TDR. Any disagreement between the reviewers was resolved by discussion.

Data analysis

From the selected studies, a meta-analysis was conducted from the extracted data only for the clinical outcomes PPD, CAL, and BOP, using RevMan Version 5.3.[19] Weighted mean change and SDs of the weighted mean change were calculated for the primary outcomes, PPD, CAL, and BOP. Where SEs of the mean (SEM) were provided in a selected study, SDs were calculated based on the sample size (SEM = SD/√N). For PPD, all studies only reported SEs or SDs for baseline and end mean values, but not for the mean change from baseline. For these studies, the SD for the mean change was imputed from the available data, assuming a correlation coefficient of 0.8 between the baseline and end mean values.[20] It was not possible to conduct a meta-analysis for microbiologic parameters and patient comfort/perception, due to insufficient data, the use of different measurements, and the limited number of studies comparing APD with conventional treatment.

REVIEW

Study comparison

Evaluation period

Most studies had an evaluation period of 3 months,[18,21,22] or 6 months.[23,24] Only one study had a duration and observation period of 2 months.[25] The shortest observation period was 7 days,[17] the longest was 12 months.[26] Data are presented in Table 3.

Population systemic and periodontal health, antibiotics taken prior to trial, and smoking status

As systemic health and the use of antibiotics can influence clinical and microbiologic parameters, the majority of studies recruited only subjects in "good general health",[17,18,21-26] in SPT with treated periodontal disease,[17,18,21-26] and with no history of taking antibiotics within the last 28 days,[17,26] 3 months,[25,21] or 6 months,[22-24] respectively. Some studies provided information on the smoking status of their subjects[17,18,22-24,36] and two studies reported smoking as an exclusion criterion[18,23] (Table 3). However, none of the studies assessed the effects of smoking on the study outcomes.

Sample size, mean age, and gender distribution

Only three studies[18,23,25] calculated sample size based on changes in PPD[25,23] and reduction in viable bacterial counts.[18] Sample size calculations were not reported in other studies.[17,22,24,26] Minimum sample size was 20 participants[25] and the maximum was 50.[26] Age range and gender distribution of the participants was not stated in one of the studies[25] (Table 3).

Test product and industry funding

Test treatment was performed using a commercially available air-polishing unit (Air-Flow Master, Electro Medical Systems [EMS]; Perio-flow handpiece and disposable nozzle) with low abrasive powders, glycine (Air-Flow PERIO powder)[17,18,21,23,25] or erythritol with 0.3% chlorhexidine (Air-Flow Powder PLUS)[22,24,26] for approximately 5 seconds per site (Table 3). All experimental products were manufactured by EMS. One study[21] did not use the nozzle because it was not available at that time. Six of the eight studies were supported by the industry,[17,18,22,24-26] one study was supported by the author's institution only,[23] and one study did not disclose any source of funding.[21]

Quality assessment outcome

The Cochrane Handbook for Systematic Reviews of Intervention version 5.1.0[20] was used in quality assessment.

Study design and randomization

All the studies selected for the systematic review and meta-analysis were RCTs. Four studies utilized a split-mouth design,[17,21,23,25] while the remaining four utilized a parallel-group design[18,22,24,26] (Table 3). The selected studies allocated sites (split-mouth) or groups of patients (parallel group design) to test and control treatment. The method of randomization was described in five studies,[17,18,21,22,26] but it was unclear in the remaining three studies.[25,23,24]

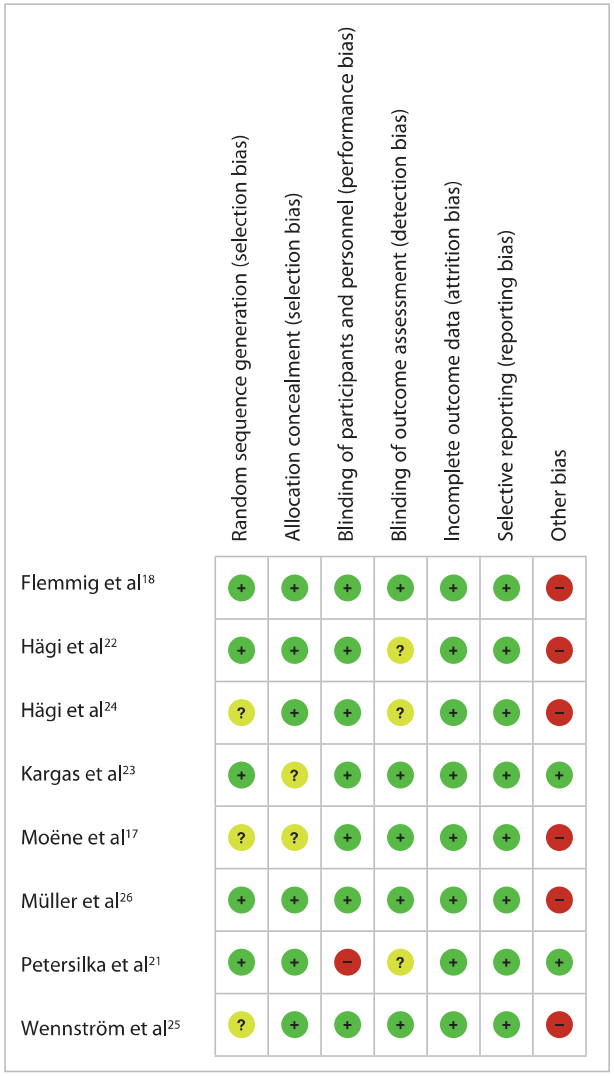

Fig 2 Risk of bias summary.

Sources of bias

Blinding procedure was not specified in five studies.[17,21,23-25] Three studies[18,22,24] were single-blinded studies with the examiner unaware of the treatment protocol conducted. Based on the Cochrane Handbook for Systematic Reviews of Intervention version 5.1.0 [updated March 2011] criteria,[20] the risk of bias was summarized and is presented in Fig 2.

Follow-up/attrition rate

One study[23] did not provide data on attrition rate. Three studies[17,18,25] reported no loss of subjects to follow-up. Four studies[21,22,24,26] reported loss of subjects; however, none of the withdrawals were mentioned to be product or procedure related. Drop outs were three patients,[21] two patients,[24] and one patient.[22,26] Also, smoking status of the patients who did not complete the study was not reported.

Data collection of primary outcomes: clinical parameters

Primary outcomes PPD, BOP, and CAL were mainly registered at six sites for single- and multi-rooted teeth. Sites with a PPD of more than 3 mm but less than 9 mm were included in the selected studies. Furcation sites were excluded in five studies,[18,21,22,24,25] two studies excluded "any physical limitations or restrictions that might preclude normal oral hygiene procedures,"[17,26] one study did not specify furcation involvement as an exclusion criteria.[23] Some of the studies precisely defined the method of PPD measurement and the method of recording,[17,24,25] whereas others did not provide clear information.[18,21] The selected studies used various periodontal probes for measuring PPD. Three studies did not report the type of probe used,[17,21,26] and four studies[22-25] used three different manual probes: PCP periodontal probe (Hu-Friedy), UNC 15 probe (Hu-Friedy), and Williams probe (POW, Hu-Friedy). A computerized periodontal probe (Florida Probe), measuring PPD to the nearest 0.2-mm increment, was used in one study.[18] BOP assessment was precisely described in two studies[18,25] as bleeding induced by probing of periodontal pockets that occurred within 15 or 30 seconds of observation. Gingival recession (GR), measured from the reference point (cementoenamel junction [CEJ] or the border of restoration) to the gingival margin, was reported as positive if located apically and negative if located coronally to the CEJ. Five studies[17,18,23,25,26] defined CAL measurement. However, it has to be noted that none of the studies used custom-made appliances/splints for measuring clinical parameters. This may affect reproducibility of data collection at different time points.

doi: 10.3290/j.qi.a40341

Table 4 Baseline–end comparisons of clinical parameters, intervention vs comparator

Parameter	Study	Intervention/comparator(s)		Baseline (SD/SE)	Intervention vs comparator, significance (*P*)	End (SD/SE)	Intervention vs comparator, significance (*P*)
Mean PPD (mm)	Wennström et al[25]	APD		5.8 (0.70)	NS	4.5 (0.87)	NS
		Ultrasonics		5.7 (0.62)		4.4 (0.93)	
	Flemmig et al[18]	APD		4.3 (0.9)	NS	4.1 (0.8)	NS
		Curettes		4.2 (0.5)		4.1 (0.5)	
	Hägi et al[22]	APD		4.46 (0.07)	.31	3.72 (0.12)	.04
		Curettes		4.64 (0.09)		4.16 (0.14)	
	Müller et al[26]	APD		5.2 (0.4)	.003	4.5 (1.0)	NS
		Ultrasonics		5.4 (0.6)		4.4 (1.1)	
	Kargas et al[23]	APD		4.78 (0.10)	NS	4.52 (0.09)	
		Ultrasonics		4.66 (0.10)		4.00 (0.08)	*
		Curettes		4.50 (0.09)		4.06 (0.10)	*
	Hägi et al[24]	APD		4.46 (0.07)	> .05	3.78 (0.13)	> .05
		Curettes		4.65 (0.09)		3.92 (0.15)	
Mean CAL (mm)	Wennström et al[25]	APD		NR	NR	−0.6 (0.69)†	NS
		Ultrasonics				−0.6 (1.3)†	
	Hägi et al[22]	APD		4.90 (0.19)	.78	4.43 (0.22)	.82
		Curettes		5.07 (0.21)		4.57 (0.25)	
	Kargas et al[23]	APD		5.42 (0.13)		5.40 (0.11)	
		Ultrasonics		5.12 (0.11)	NS	4.82 (0.11)	*
		Curettes		4.94 (0.09)	*	4.82 (0.09)	*
	Hägi et al[24]	APD		4.90 (0.19)	> .05	4.43 (0.24)	> .05
		Curettes		5.07 (0.21)		4.37 (0.6)	
BOP (%)	Moene et al[17]	APD	S	73 (29)	NS	58 (35)	.045
		Curettes		68 (39)		43 (35)	
	Wennström et al[25]	APD	FM	100	NS	25	NS
		Ultrasonics		100		30	
	Flemmig et al[18]	APD	S	26.8 (27.9)	NS	14.0 (20.6)	NS
		Curettes		33.6 (17.9)		16.8 (16.3)	
	Hägi et al[22]	APD	FM	31.70 (2.31)	.25	26.10 (2.45)	.24
		Curettes		36.45 (2.84)		30.89 (2.84)	
	Müller et al[26]	APD	S	58 (50)	NS	15 (6)	NS
		Ultrasonics		48 (50)		14 (6)	
	Hägi et al[24]	APD	FM	31.70 (2.31)	> .05	26.11 (2.90)	> .05
		Curettes		36.45 (2.84)		27.89 (2.52)	

APD, air polishing device; BOP, bleeding on probing; CAL, clinical attachment level; FM, full mouth; NR, not reported; NS, no statistical significance; PPD, probing pocket depth; S, site specific; *Statistical significance between APD and comparator and other groups (Bonferroni's test). †Negative value present: RAL (relative attachment gain).

Data collection of secondary outcomes: microbiologic parameters and patient discomfort/ tolerance

The secondary outcome, microbiologic parameters, was tested at different time points; baseline, immediately after treatment, as well as 2, 10, and 12 days, and 3, 6, and 12 months following the SPT. Subgingival plaque samples were collected with sterile paper points inserted to the bottom of the periodontal pocket and left in situ for 10 seconds[17,18,21,26] or 30 seconds.[24]

Two studies collected subgingival plaque with a sterile curette.[23,25] In four studies,[18,21,23,25] in order to minimize contamination, supragingival plaque was removed and sampling was done prior to measuring clinical parameters.

Patient comfort was evaluated using a VAS in six studies.[17,18,21,22,25,26] One study did not specify the method of evaluation of discomfort/pain perception[24] and one study[23] used a questionnaire with a scale of 0 to 4 to assess patient perception of pain, cold, and pressure during treatment as well as the patient's preferred technique. Safety of the treatment was monitored in all trials.

Systematic review and meta-analysis outcomes

Comparison between groups intervention APD (GPAP or EPAP) vs conventional treatment baseline–end of the treatment

Table 4 summarizes baseline–end of treatment clinical outcome (PPD, BOP, CAL) differences between APD and conventional treatment. No differences were found when comparing APD vs comparator intervention in PPD and CAL, except for one study. Kargas et al[23] reported a significant difference at three time points (1, 3, and 6 months; results not shown for 1 and 3 months). The difference was in favor of conventional treatment. However, the subsequent meta-analysis of pooled data showed there was no significant difference in the mean changes between APD and conventional treatment for PPD (MeanDiffΔPD = 0.05; $P = .34$; 95% confidence interval [CI], −0.05 to 0.15) and CAL (MeanDiffΔCAL = −0.17; $P = .11$; 95% CI, −0.37 to 0.04) (Table 5). Full mouth or site BOP was not significantly different at any time point between intervention and comparator groups. Inevitably, the meta-analysis also showed that there was no significant difference in the change in proportion of BOP between APD and conventional treatment (MeanDiffΔBOP = 0.01; $P = .26$; 95% CI, 0.00 to 0.02) (Table 5).

Microbiologic analysis (Table 6) revealed a general trend of reduction in bacterial load immediately and in the short term after intervention with APD and conventional treatment modalities. Two studies[18,21] found a significantly higher reduction in bacterial load in the intervention group (APD) 10 days and 3 months following the treatment. A meta-analysis of microbiologic outcomes was not possible due to the heterogeneity in measurement methods and outcomes.

As treatment was conducted without administration of local anesthetic, the participants were asked to evaluate the perception of discomfort during the treatment. In five studies[17,18,22,25,26] a VAS scale was used for the evaluation of discomfort, from 0 representing no discomfort to 10 representing high discomfort or pain. Petersilka et al[21] also utilized a VAS scale to evaluate patients' tolerance to either treatments. However, contrary to other studies, a value of 0 represented the highest discomfort, while a value of 10 represented no discomfort. Unfortunately, a meta-analysis could not be performed for patients' perception of discomfort due to a lack of data and the variance in measured pain scales used.

DISCUSSION

The instrument end point of a periodontal maintenance appointment is an empty curette, ie no visible plaque on the surface of the working end when it exits the sulcus.[27] Patients on a maintenance program should already have smooth roots, as subgingival deposits on root surfaces should have been removed during initial periodontal therapy.[27] APDs are theoretically thought to be more effective than conventional treatments at removing biofilms because the stream of abrasive particles is able to remove biofilm remnants that hand instrumentation may leave behind.[15] At present, no systematic quantitative evaluation with a meta-analysis approach, focusing on the APD as a monotherapy during periodontal maintenance has been performed. This study aimed to evaluate this treatment modality from an evidence-based perspective.

Treatment outcomes

The primary outcome of this study was to use clinical parameters (PPD, BOP, and CAL) to assess if APD (inter-

doi: 10.3290/j.qi.a40341

Table 5 Meta-analysis of probing depth (PPD), clinical attachment level (CAL), and bleeding on probing (BOP) outcomes

Parameter	Study	APD N	APD Mean	APD SD	Conventional N	Conventional Mean	Conventional SD	Weight (%)	Mean difference	95% CI	*P* value
PPD	Wennström et al[25]	20	−1.30	0.52	20	−1.30	0.57	8.5	0.00	−0.34 – 0.34	
	Flemmig et al[18]	15	−0.20	0.55	15	0.10	0.32	9.6	0.10	−0.42 – 0.22	
	Hägi et al[22]	91	−0.74	0.73	87	−0.48	0.81	19.1	−0.26	−0.49 – −0.03	
	Müller et al[26]	50	−0.70	0.72	50	−1.00	0.72	12.4	0.30	0.02 – 0.58	
	Kargas et al[23]	25	−0.26	0.30	25	−0.44	0.30	34.6	0.18	0.01 – 0.35	
	Hägi et al[24]	89	−0.68	0.80	87	−0.73	0.89	15.7	0.05	−0.20 – 0.30	
	All	290			284			100.0	0.05	−0.05 – 0.15	.34
CAL	Wennström et al[25]	40	−0.60	0.69	40	−0.60	1.30	20.0	0.00	−0.46 – 0.46	
	Hägi et al[22]	91	−0.47	1.27	87	−0.50	1.40	27.3	0.03	−0.36 – 0.42	
	Kargas et al[23]	25	−0.02	3.91	25	−0.12	0.29	1.8	0.10	−1.44 – 1.64	
	Hägi et al[24]	89	−0.47	1.36	87	−0.12	0.29	50.6	−0.35	−0.64 – −0.06	
	All	245			239			100.0	−0.17	−0.37 – 0.04	.11
BOP	Moëne et al[17]	50	−0.15	0.09	50	−0.25	0.10	9.8	0.10	0.06 – 0.14	
	Wennström et al[25]	40	−0.75	0.07	40	−0.70	0.07	14.5	−0.05	−0.08 – −0.02	
	Flemmig et al[18]	15	−0.13	0.15	15	−0.17	0.16	1.2	0.04	−0.07 – 0.15	
	Hägi et al[22]	91	−0.06	0.07	87	−0.06	0.07	32.6	0.00	−0.02 – 0.02	
	Müller et al[26]	50	−0.27	0.10	50	−0.21	0.10	9.7	−0.06	−0.10 – −0.02	
	Hägi et al[24]	89	−0.06	0.07	87	−0.09	0.07	32.3	0.03	0.01 – 0.05	
	All	335			329			100.0	0.01	−0.00 – 0.02	.26

vention) was a viable alternative to conventional treatment (comparator) in a population of patients on SPT. Due to inherent heterogeneity of the various studies, a random-effects model was used for the meta-analysis. Based on pooled data across selected studies, it was found that APDs offer similar clinical treatment outcomes regarding effect on clinical parameters (PPD, BOP, and CAL) when compared to conventional treatment in SPT. A possible explanation for this finding is that both APDs and conventional treatment modalities seem to have similar capability in removing subgingival biofilm. Numbers of periodontal pathogens generally return to pretreatment levels in 9 to 11 weeks post-treatment.[28] After the reformation of biofilm, there is a lag phase before its disease-producing ability is regained.[27] Mechanical removal or disruption of any established supragingival and subgingival biofilm that has formed since the last SPT visit is an essential component of periodontal maintenance.[27] This result indicates that both treatment methods, APD and conventional treatment, can be used successfully to reduce the number of pathogens in the subgingival biofilm before they regain their full pathogenic potential to further damage periodontal tissues.

As mentioned previously, due to differences in reporting and methods used to quantify microbiologic parameters, it was not possible to perform meta-analysis on the secondary outcomes. Following intervention treatment, only two studies[18,21] found a significant reduction in bacterial load after 10 days and 3 months in the APD group. This may be due to the presence of shallow pockets only in the study by Petersilka et al,[21] and in additionally conducted full-mouth debridement and use of 0.12% chlorhexidine mouthwash for 2 weeks in the study of Flemmig et al.[18] The remaining studies observed no differences between groups at any time point. It is evident that although intervention with APDs may be associated with a general trend of addi-

Table 6 Microbiologic results

Study	Intervention/ comparator	Sites, residual pockets	Sampling method, time and tests	Baseline intergroup comparison	End intergroup comparison	Baseline vs end intragroup comparison
Petersilka et al[21]	APD (test)	Buccal/ lingual sites; PDD = 3–5 mm; No furcations	Paper point 10 s	log 4.71 ± 1.09	log 1.69 ± 0.98‡	NA
	Curettes (+ control)		Baseline – 3 mo	log 4.37 ± 0.94	log 0.61 ± 0.79‡*	
	No treatment (– control)		logCFU/stereomicroscope	log 4.37 ± 0.94	log 0.06 ± 0.49*	
				NS	$P < .05$	
Moëne et al[17]	APD	Sites with PDD ≥ 5 mm. Incisor – second molar	Paper point 10 s; –2 d (baseline) – 7 d; Real time PCR; Total bacterial load (TBL); *Aa*, *Fn*, *Pg*, *Pi*, *Td*, *Tf* (frequency % and mean count in positive samples)	*Aa* 14 (4,135)	*Aa* 10 (6,820)	NA
				Fn 64 (82, 787)	*Fn* 56 (259, 974)	NA
				Pg 44 (401, 970)	*Pg* 36 (1,108, 729)	NA
				Pi 32 (221, 557)	*Pi* 28 (217, 687)	NA
				Td 52 (329, 161)	*Td* 48 (219, 353)	NA
				Tf 60 (275, 317)	*Tf* 56 (337, 922)	NA
	Curettes			*Aa* 12 (15, 255)	*Aa* 14 (1, 8111)	NA
				Fn 60 (156, 171)	*Fn* 60 (164, 076)	NA
				Pg 44 (1, 635, 074)	*Pg* 36 (592, 911)	.01
				Pi 24 (118, 758)	*Pi* 20 (16, 672)	NA
				Td 58 (444,442)	*Td* 42 (183, 987)	.001
				Tf 68 (391, 808)	*Tf* 52 (129, 154)	.001
				NS	NS	NA
Wennström et al[25]	APD	Sites with PDD = 5–8 mm; No furcations	Sterile curette; Baseline: immediately posttreatment, 2–14 d; Checker-board DNA-DNA hybridization; *Pg*, *Pi*, *Pn*, *Tf*, *Aa*, *Fn*, *Td*, *Pm*, *Cr*, *Pe*, *Fa*, *Pt*; Number of sites positive for the various microbial species (≥ 10^5)	There was a general trend of reduced number of positive sites immediately and 2 d after APD and ultrasonic debridement. At d 14 the recovery rates returned to figures comparable to those before treatment. At baseline as well as at the post treatment, none of the analyses revealed any statistically significant differences between APD and ultrasonic debridement.	NA	NA
	Ultrasonics				NA	NA
Flemmig et al[18]	APD	Sites with PDD = 4–9 mm	Paper point 10 s; Baseline: immediately post treatment – 10 and 90 d; Real time PCR; *Pg* and *Tf* (frequency % and log CFU calculated by the use of standard curve)	Immediately and at d 10; APD vs curettes; APD significantly lower viable bacterial counts compared with curettes; At d 90 viable bacterial counts returned to baseline in both groups	< .05	NA
	Curettes					
Müller et al[26]	APD	PDD > 4 mm	Paper point 10 s; Baseline – 12 mo; Real time PCR; *Aa*, *Pg*, *Tf*, *Td*, *Pi*, *Pm*; Site positive detection	The frequencies of the studies microorganisms at > 1000 and > 100,000 cells/mL were not significantly different at baseline and 12 mo later. At 12 mo *Aa* was lower in test group but it was not statistically significant.	NA	NA
	Ultrasonics					
Kargas et al[23]	APD	Sites with PDD > 4 mm; Non-bleeding	Sterile curette; Baseline –1, 3, and 6 mo; Checker-board DNA-DNA hybridization; *Pg*, *Td*, *Tf*; Number of investigated species (≥ 10^5)	No differences were observed among groups regarding numbers of the three investigated bacteria at any time point.	NA	NA
	Ultrasonics					
	Curettes					
	No treatment					
Hägi et al[24]	APD	Sites with PDD ≥ 4 mm	Paper point 30 s; Baseline – 6 mo; Semi-quantitative PCR; *Aa*, *Pg*, *Pi*, *Tf*, *Td*, *Pm*, *Fn*, *Cr*, *En*, *Ec*, *Capnocytophaga* species	The counts of periodontopathogens (*Aa*, *Pg*, *Td*, *Tf*) did not change significantly during therapy either in the test or in the control group.	NA	NA
	Curettes					

*+ control vs – control, statistically significant difference at 3 months.
‡Test vs + control, statistically significant difference at 3 months.
Aa, *Aggregatibacter actinomycetemcomitans*; APD, air polishing device; CFU, colony forming units; *Cr*, *Campylobacter rectus*; *Ec*, *Eikenella corrodens*; *En*, *Eubacterium nodatum*; *Fa*, *Filifactor alocis*; *Fn*, *Fusobacterium nucleatum*; NA, not applicable; PCR, polymerase chain reaction; *Pe*, *Porphyromonas endodontalis*; *Pg*, *Porphyromonas gingivalis*; *Pi*, *Prevotella intermedia*; *Pm*, *Parvimonas micra*; *Pn*, *Prevotella nigrescens*; PPD, probing pocket depth; *Pt*, *Prevotella tannerae*; *Td*, *Treponema denticola*; *Tf*, *Tannerella forsythia*.

doi: 10.3290/j.qi.a40341

tional reduction in bacterial load in the short term, this microbiologic difference seems to be not robust enough to last for more than 3 months.

Regarding patient perception of pain or discomfort, the results were in favor of APD in all studies that tested tolerance,[17,21-23,25,26] except one.[18] This suggests that APDs may be associated with less discomfort than conventional treatment, a finding consistent with a study by Buhler et al.[29] Mean debridement time was only reported by one study.[17] The authors found that the use of APD with glycine powder resulted in faster debridement (0.5 minutes/site), with no clinically visible hard and soft tissue damage compared to hand instrumentation (1.4 minutes/site).[17]

APD advantages and patient preference

Based on the present findings that both treatment modalities, APDs and conventional mechanical debridement, show a similar efficacy in removing subgingival biofilm, the use of APDs may be a better choice because mechanical debridement has been shown to cause more damage to the periodontium. Repeated mechanical instrumentation of the root surfaces with curettes or ultrasonics has been shown to potentially cause irreversible hard tissue damage,[17] whereas the risk of excessive root substance removal has been shown to be negligible if an APD in conjunction with low abrasive powders is used.[18] Even though there may be no observable clinical difference in the appearance of periodontal tissues after APDs or curettes have been used, curettes have been shown histologically to cause greater soft tissue damage.[15] Conversely, it has been demonstrated that the oral gingival epithelium remains intact after an APD has been used.[15] Besides causing damage during debridement, subgingival insertion of curettes also leads to damage and removal of some gingival and junctional epithelium.[15] Debridement using hand instruments or ultrasonic scalers is also technically demanding and time-consuming. In contrast, the use of an APD has been shown to result in nearly complete plaque removal within 5 to 10 seconds per root surface,[15] making it more time-efficient during SPT.[17] There is also consensus in the literature that the use of an APD is associated with greater patient comfort than other forms of mechanical debridement.[15,17,25,30] This could be significant, given the large attrition rate of patients undergoing SPT.[31]

Limitations

Studies included in the review and meta-analysis employed two study designs: split-mouth and parallel groups. Split-mouth design is commonly used in clinical trials assessing the different treatment modalities because it requires fewer participants and minimizes inter-individual variability that could influence the results of treatment.[32] A potential limitation of the split-mouth design is the "leaking effect" from the test (APD) to the control side (conventional treatment), particularly when microbiologic parameters are being assessed. As most studies used subgingival nozzles inserted into the pockets (except Petersilka et al[21]), it may be assumed that the "leaking effect" was less likely to occur and probably is negligible. On the other hand, inclusion of smokers in some studies may have influenced both clinical and microbiologic parameters, as smoking can have effects on the outcome of nonsurgical periodontal therapy.[33] Nevertheless, the studies that included smokers did not perform any cluster analysis, and due to heterogeneity in study design and poor reporting, this could not be analyzed. The clinical effects of periodontal parameters should be interpreted with caution as the observation period in some studies was very short (7 days) to show any realistic improvements on periodontal healing or clinical outcome, as healing of periodontal tissues requires more than 1 week. It is also important to note that the findings in the selected studies were limited to single-rooted and multi-rooted teeth with no furcation involvement.

Although data on subgingival reductions of periodontal pathogens were not the primary focus of this review, it is important to emphasize sources of heterogeneity concerning the sampling methods used as well as processing of the microbiologic samples. That also precluded the meta-analysis and synthesis of the results of the included studies. Two studies utilized a

sterile curette to obtain samples of subgingival plaque.[18,25] This method is described as the most sensitive because it manly depends on the conducting person and can also disturb the subgingival microbial ecosystem significantly more than sampling with paper points. However, subgingival biofilm sampling with sterile paper points is considered less successful for sampling the apical portion of a pocket, where more pathogens are expected to reside.[34]

It is also important to keep in mind that selected studies employed different microbiologic methods to assess and analyze subgingival plaque samples. Petersilka et al[21] cultivated samples for 7 days and quantified the number of colony forming units (CFU). Four studies[17,18,24,26] quantified different periopathogens, mainly *Aggregatibacter actinomycetemcomitans*, *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola*, by using real-time polymerase chain reaction (qPCR). Two studies[23,25] utilized the checkerboard DNA-DNA hybridization technique. Previous studies on the comparison of different methods for identification of microorganisms isolated from deep periodontal pockets, showed superiority of qPCR over culture technique and checkerboard DNA-DNA hybridization. Real-time qPCR assay is also very easy to perform, and demonstrates excellent detection limits and very little cross-reactivity under optimal conditions. Therefore, it should be the preferred method for identification of periodontal pathogens today.[35]

Furthermore, in the light of relatively recent developments and extended indications of APDs and the implemented industrial interest, the risk of publication bias must be considered to be high.

CONCLUSION

This review and meta-analysis indicates that the use of APDs as monotherapy showed similar efficacy to conventional therapy (ultrasonics and/or hand instrumentation), in patients undergoing SPT. This result is with respect to clinical parameters (PPD, BOP, and CAL) in single- and multi-rooted teeth with no furcation involvement. Data on the treatment of furcation-involved teeth are still limited. Regarding microbiologic parameters, both treatment modalities are effective in reducing bacterial load. While APDs may be associated with an initial advantage in reducing bacterial load, no statistically significant difference could be observed after 3 months. The present findings also suggest that patients are more likely to tolerate treatment with an APD, compared to conventional treatment, because of the lower perception of pain. Since patients on a frequent periodontal maintenance program are less likely to accumulate subgingival calculus, they would benefit from a less aggressive treatment. From a clinician's point of view, two aspects that could render APD as the preferred treatment method in SPT patients are less discomfort for patients and faster biofilm removal.

Future directions

Suggestions for further research on APDs as monotherapy in SPT could be to:

- cluster the patients with different residual periodontal pockets
- investigate the effects on multi-rooted teeth with furcation involvement
- investigate the impact of smoking
- measure the duration of the treatment method, by using full-mouth biofilm removal as an end point
- standardize assessment of clinical parameters
- standardize subgingival plaque sampling methods and methods of microbiologic analysis
- standardize VAS scale as a tool to assess patient comfort
- conduct long-term studies of at least 6 months to 1 year.

ACKNOWLEDGMENT

The study was self-funded by the authors and their institutions. The authors thank Victor Saverimuttu, Li Ann Ooi, Michael Wai-Shing, and Sal Sahidi for their support at the start of conducting this systematic review; also thanks to Lajos Bordas, Academic Liaison Librarian Dentistry, Westmead Clinical School and Northern Clinical School, who assisted with the search strategy and helped retrieve full-text articles.

doi: 10.3290/j.qi.a40341

REFERENCES

1. Lang NP, Tonetti MS. Periodontal risk assessment (PRA) for patients in supportive periodontal therapy (SPT). Oral Health Prev Dent 2003;1:7–16.
2. Dentino A, Lee S, Mailhot J, Hefti AF. Principles of periodontology. Periodontol 2000 2013;61:16–53.
3. Renvert S, Persson GR. Supportive periodontal therapy. Periodontol 2000 2004;36:179–195.
4. Sbordone L, Ramaglia L, Gulletta E, Iacono V. Recolonization of the subgingival microflora after scaling and root planing in human periodontitis. J Periodontol 1990;61:579–584.
5. [No authors listed] Peri-implant mucositis and peri-implantitis: a current understanding of their diagnoses and clinical implications. J Periodontol 2013;84:436–443.
6. Aimetti M. Nonsurgical periodontal treatment. Int J Esthet Dent 2014;9:251–267.
7. Fischer C, Wennberg A, Fischer RG, Attstrom R. Clinical evaluation of pulp and dentine sensitivity after supragingival and subgingival scaling. Endod Dent Traumatol 1991;7:259–265.
8. Latheef P, Sirajuddin S, Gundapaneni V, Mn K, Apine A. Iatrogenic damage to the periodontium caused by periodontal treatment procedures. Open Dent J 2015;9:203–207.
9. Pihlstrom BL, Hargreaves KM, Bouwsma OJ, Myers WR, Goodale MB, Doyle MJ. Pain after periodontal scaling and root planing. J Am Dent Assoc 1999;130:801–807.
10. West NX, Lussi A, Seong J, Hellwig E. Dentin hypersensitivity: pain mechanisms and aetiology of exposed cervical dentin. Clin Oral Investig 2013;17 (Suppl 1):S9–S19.
11. Lin YH, Gillam DG. The prevalence of root sensitivity following periodontal therapy: a systematic review. Int J Dent 2012;2012:407023.
12. Leknes KN. The influence of anatomic and iatrogenic root surface characteristics on bacterial colonization and periodontal destruction: a review. J Periodontol 1997;68:507–516.
13. Brayer WK, Mellonig JT, Dunlap RM, Marinak KW, Carson RE. Scaling and root planing effectiveness: the effect of root surface access and operator experience. J Periodontol 1989;60:67–72.
14. Leknes KN, Lie T, Wikesjo UM, Bogle GC, Selvig KA. Influence of tooth instrumentation roughness on subgingival microbial colonization. J Periodontol 1994;65:303–308.
15. Petersilka GJ. Subgingival air-polishing in the treatment of periodontal biofilm infections. Periodontol 2000 2011;55:124–142.
16. Flemmig TF, Hetzel M, Topoll H, Gerss J, Haeberlein I, Petersilka G. Subgingival debridement efficacy of glycine powder air polishing. J Periodontol 2007;78:1002–1010.
17. Moëne R, Decaillet F, Andersen E, Mombelli A. Subgingival plaque removal using a new air-polishing device. J Periodontol 2010;81:79–88.
18. Flemmig TF, Arushanov D, Daubert D, Rothen M, Mueller G, Leroux BG. Randomized controlled trial assessing efficacy and safety of glycine powder air polishing in moderate-to-deep periodontal pockets. J Periodontol 2012;83:444–452.
19. Review Manager (RevMan)[Computer program]. Version 5.3. Copenhagen: The Nordic Cochrane Centre TCC, 2014.
20. Higgins JPT, Green S. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011.
21. Petersilka GJ, Steinmann D, Haberlein I, Heinecke A, Flemmig TF. Subgingival plaque removal in buccal and lingual sites using a novel low abrasive air-polishing powder. J Clin Periodontol 2003;30:328–333.
22. Hägi TT, Hofmanner P, Salvi GE, Ramseier CA, Sculean A. Clinical outcomes following subgingival application of a novel erythritol powder by means of air polishing in supportive periodontal therapy: a randomized, controlled clinical study. Quintessence Int 2013;44:753–761.
23. Kargas K, Tsalikis L, Sakellari D. Pilot study on the clinical and microbiological effect of subgingival glycine powder air polishing using a cannula-like jet. Int J Dent Hyg 2015;13:161–169.
24. Hägi TT, Hofmanner P, Eick S, et al. The effects of erythritol air-polishing powder on microbiologic and clinical outcomes during supportive periodontal therapy: six-month results of a randomized controlled clinical trial. Quintessence Int 2015;46:31–41.
25. Wennström JL, Dahlen G, Ramberg P. Subgingival debridement of periodontal pockets by air polishing in comparison with ultrasonic instrumentation during maintenance therapy. J Clin Periodontol 2011;38:820–827.
26. Müller N, Moëne R, Cancela JA, Mombelli A. Subgingival air-polishing with erythritol during periodontal maintenance: randomized clinical trial of twelve months. J Clin Periodontol 2014;41:883–889.
27. Armitage GC, Xenoudi P. Post-treatment supportive care for the natural dentition and dental implants. Periodontol 2000 2016;71:164–184.
28. Greenstein G. Periodontal response to mechanical non-surgical therapy: a review. J Periodontol 1992;63:118–130.
29. Buhler J, Amato M, Weiger R, Walter C. A systematic review on the effects of air polishing devices on oral tissues. Int J Dent Hyg 2016;14:15–28.
30. Sculean A, Bastendorf KD, Becker C, et al. A paradigm shift in mechanical biofilm management? Subgingival air polishing: a new way to improve mechanical biofilm management in the dental practice. Quintessence Int 2013;44:475–477.
31. Mendoza AR, Newcomb GM, Nixon KC. Compliance with supportive periodontal therapy. J Periodontol 1991;62:731–736.
32. Lesaffre E, Philstrom B, Needleman I, Worthington H. The design and analysis of split-mouth studies: what statisticians and clinicians should know. Stat Med 2009;28:3470–3482.
33. Labriola A, Needleman I, Moles DR. Systematic review of the effect of smoking on nonsurgical periodontal therapy. Periodontol 2000 2005;37:124–137.
34. Loomer PM. Microbiological diagnostic testing in the treatment of periodontal diseases. Periodontol 2000 2004;34:49–56.
35. Kotsilkov K, Popova C, Boyanova L, Setchanova L, Mitov I. Comparison of culture method and real-time PCR for detection of putative periodontopathogenic bacteria in deep periodontal pockets. Biotechnol Biotechnologic Equip 2015;29:996–1002.