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SYSTEMATIC REVIEWS AND META-ANALYSIS

Effects of air abrasive decontamination on titanium surfaces: A systematic review of in vitro studies

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Abstract

Background: Air abrasion (AA) is one of the decontamination methods that have demonstrated promising results in treating peri-implant diseases.

Purpose: This systematic review aimed at evaluating the in vitro effect of AA on surface change, cleaning efficacy, and biocompatibility of titanium surfaces and at comparing it with other decontamination methods.

Materials and Methods: A comprehensive search was conducted up to April 2018 using PubMed, Scopus, and Google Scholar databases to identify studies on the decontamination effect of AA. All types of titanium surfaces, abrasive powders, contaminated surfaces, and measuring methods were included.

Results: Overall, 1502 articles were identified. After screening the titles and abstracts, and carefully reading the full-texts, 48 articles published between 1989 and 2018 were selected. AA was considered almost safe, particularly for the nonmodified surfaces. Nevertheless, harder powders such as sodium bicarbonate tended to damage the surface more than glycine. AA resulted in surface change similar to plastic curettes and Er: YAG lasers. Regarding the cleaning efficacy, there was no significant difference between glycine and sodium bicarbonate, but different mixtures of calcium phosphate, hydroxyapatite, and erythritol were superior to glycine. AA was superior or equal to all other decontamination methods in cleaning. Regarding biocompatibility, AA was more successful in preserving biocompatibility for noncontaminated surfaces compared with contaminated surfaces and when used with erythritol and osteoinductive powders.

Conclusions: AA can efficiently remove contamination without serious damage to the surface. The main drawback of the AA method seems to be its limitation in restoring the biocompatibility of the surface.

KEYWORDS
air abrasion, biocompatibility, cleaning effectiveness, decontamination, surface roughness, titanium surface

1 | INTRODUCTION

The inflammatory process around an implant, characterized by soft tissue inflammation and loss of supporting marginal bone, is called peri-implantitis.[1,2] Overall, peri-implant mucositis, the precursor of peri-implantitis, occurs in approximately 50% of the implants and 80% of the patients, and peri-implantitis itself affects around 12% to 43% of implants and 28% to 56% of patients.[2] The main reason for peri-implantitis is the imbalance between the bacterial load and host defense at the mucosal tissue-implant interface, which is associated with predominantly Gram-negative anaerobic flora.[3] As the formation of a biofilm on the implant surface plays a significant etiological role,[4,5] the treatment of peri-implant mucositis and peri-implantitis must include removal of biofilm to restore the peri-implant health condition.[6,7]

Decontamination procedures consist of surgical and nonsurgical interventions that adopt a series of different devices such as mechanical instruments (eg, titanium, plastic, and steel curettes, ultrasonic scalers, cotton gauze, and air abrasion [AA]) or nonmechanical approaches (eg, lasers, chlorhexidine, tetracycline, metronidazole, and citric acid) which can also be combined. Nevertheless, no recognized gold standard for the treatment of peri-implantitis has been suggested.[8–10] Mechanical debridement can potentially change the implant surface roughness and also induce alterations to the chemical oxide layer which impairs the adhesion of fibroblasts and thus disrupts the biocompatibility of the implant.[11]

The search for an efficient and safe approach for titanium surface decontamination resulted in a novel method, the AA treatment. Air-polishing devices were first introduced to dentistry in 1945[12] and have been used for mechanical tooth cleaning since the 1980s.[13,14] The AA technology was firstly developed for the supragingival cleaning or polishing of natural teeth surfaces using sodium bicarbonate (SB). With the development of glycine powders, the subgingival application was also proven to be safe and more efficient than mechanical scaling and root planning for removing the biofilm in moderate to deep periodontal pockets.[15,16] AA was also tested on implant surfaces, and some studies showed that it successfully removed the biofilm from the titanium surface without serious damage.[17,18] AA system was even reported to be superior in cleaning and preserving the implant surfaces compared to curettes or ultrasonic scalers.[19,20]

Several systematic reviews are available in the scientific literature about the AA method,[19,21–24] but most of these studies generally concentrated on mechanical debridement treatments rather than on AA specifically. Furthermore, these reviews mainly focused on a particular outcome, not providing a comprehensive view, or only reported clinical results without correlating them with the parameters of AA systems (eg, device settings and powders) or the features of titanium surfaces (eg, roughness and compositions), so not providing a deep understanding of the mechanisms of AA systems which can lead to the further improvements.

Therefore, the present systematic review aimed at evaluating the in vitro effects of AA on surface change (morphology, topology, composition), cleaning efficacy, and biocompatibility of titanium surfaces and at comparing it with other decontamination methods.

2 | MATERIALS AND METHODS

2.1 | Protocols

This systematic review was prepared according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement.[25] The current review addresses clearly a focused question by using the participant, intervention, comparison, and outcomes (PICO) criteria.[26,27]

2.2 | Search Strategy

Three electronic databases (PubMed, Google Scholar, and Scopus) were used to identify publications that met the inclusion criteria. The search was conducted up to April 2018, using the following terms and keywords alone or in combination: Air Abrasive, Air Abrasion, Air Polishing, Abrasive Powder, Titanium, Decontamination, Implant, Surface Roughness, Biocompatibility, Viability, Instrument, Prophy Jet, Hygiene Instrument. Moreover, reference lists of the selected studies were manually screened. The publication dates ranged from 1989 to 2018.

2.3 | Eligibility criteria

The following inclusion criteria were used to assess the studies:

1. Published in a peer-review journal;
2. Being an original article with an in vitro decontamination procedure, in English;
3. Reporting on titanium dental implant surface, or titanium discs, strips, and cylinders;
4. Reporting on the cleaning effectiveness or surface change or biocompatibility;
5. All types of titanium materials and surfaces such as pure, alloyed, nonmodified (smooth surface), and modified (rough surface) were included;
6. AAs with and without abrasive powders were included;
7. Both biofilms obtained from the oral cavity and cultured in laboratories were acceptable to determine the in vitro efficacy of an AA device;

The studies were excluded based on these criteria:

1. In vivo studies, clinical reports;
2. Studies on teeth and other restorative materials other than titanium;
3. Studies on the efficacy of AA in combination with other methods, not allowing an assessment of the efficacy of AA device alone.

2.4 | Focused PICO question

2.4.1 | What is the effect of air-abrasive decontamination on titanium surfaces?

Participants: Titanium surface whether pure or alloyed, modified or nonmodified, coated, or noncoated.

Intervention: Decontamination using AA devices.

Comparison: Among different types of AA instruments with different settings and powders; with untreated controls; with other decontamination methods.

Outcomes: Surface changes and cleaning effectiveness (primary); biocompatibility (secondary).

2.5 | Selection of studies

Two reviewers (M.M. and V.P.) independently screened the retrieved citations and identified relevant studies after removing the duplications. Title management was performed electronically by a commercially available software program (Endnote X7, Thomson, London, UK). Removal of duplicate studies was conducted internally in each database and by comparing the results against other databases. The eligibility for initial citations was assessed by the title, abstract, and keywords. The full texts of potentially relevant articles were then obtained and assessed using an eligibility form. Any disagreements on the selection of studies were resolved by discussion and the reasons for excluding irrelevant articles were reported.

2.6 | Data collection

The following information was extracted independently from each study by the two Authors (M.M. and V.P.), using a predesigned data extraction form:

Title, Authors' names, contact address, study location, language of publication, year of publication, published or unpublished data, study design, method of randomization, duration of study, number of specimens, surface modification, surface contamination method, type and brand of AA device, settings for AA device, type of powder and particle size, decontamination devices other than AA and their settings, method of measurements, outcome variables.

2.7 | Data analysis

Considerable methodological and clinical heterogeneity were found in the selected studies regarding participants, interventions, and outcome measures. Evident differences were seen in study design, methodologies, titanium surface modifications, AA device settings, treatment modalities, outcome measures, and results. Moreover, many studies only reported qualitative results with only descriptive or graphic representation and a standardized system lacked. Finally, only a few studies performed the statistical analysis of the data; therefore, the comparison between studies was not feasible, and a descriptive presentation of the data had to be adopted since meta-analysis was considered inappropriate.[28,29] However, when possible, quantitive data were presented. Moreover, when applicable, based on each study's categorization and criteria, the descriptive results were arranged ordinally, and comparisons were made within each factor. Any disagreement between the two reviewers (M.M. and V.P.) was resolved after additional discussion or after judgment by a third reviewer (AQ).

3 | RESULTS

3.1 | Search and selection

The search resulted in 1502 unique articles. The initial screening of the titles and abstracts identified 58 full texts. After reading the full-text articles, 10 articles were excluded: three articles due to using the AA in combination with other decontamination methods,[30–32] one study was not about titanium surface,[33] two articles did not use AA for decontamination,[34,35] one study was not in English and not published in a peer-review journal,[36] one study used the AA powder in an antimicrobial solution but did not use the AA device,[37] one study had an in vivo design with decontamination procedures taking place in the beagle dogs,[38] and the full text for one study was not retrieved.[39] The 48 included articles were ultimately processed for data extraction.[17,18,20,40–84] The summary of the search strategy is depicted in Figure 1.

3.2 | Subdivision of selected studies

The characteristics of the 48 selected studies have been reported in chronological order in Table 1. It is noteworthy to mention that out of 48 included studies, only 11 studies employed devices to standardize the decontamination procedure and avoid the clinician erroneous,[41,46,47,49,50,68,71,72,74,82,84] and only one study used a phantom head to simulate clinical conditions.[78]

Based on the comparisons, the studies were categorized into two main groups:

1. Twenty-two out of forty-eight articles compared different AA devices and powders with each other
2. Twenty-six out of forty-eight articles compared AA with other decontamination methods

Moreover, in each group, the articles could be further subdivided according to the outcome measures:

1. Surface change (ie, morphology, topology [roughness], and composition);
2. Cleaning efficacy;
3. Biocompatibility (ie, cell and bacterial viability, attachment, growth, and proliferation).

It should be noted that some studies were presented in more than one subdivision as they addressed different outcomes measures.

3.3 | Comparison between the air-abrasive methods

3.3.1 | Surface change

Fourteen studies were included in this category (Table 2). The publication dates of the articles ranged from 1989 to 2018. All the 14 studies reported on the morphology of the surface using the qualitative output of the scanning electronic microscope (SEM), but only three studies [41,43,45] provided topological assessment and evaluated surface roughness quantitatively. Regarding the SEM results, except for three studies that reported no surface change,[40,47,50] other studies showed some level of morphological changes which were different in nature and intensity based on the surface modification and powder type. Regarding the surface topology, 2 studies showed that the Ra value for SB was higher than glycine and untreated controls [41,45] while another study found no difference.[43] Six articles reported on surface composition using energy dispersive-x spectrometry (EDS) [41,44,46,47,50,51] from which except for one study,[41] others found powder remnants and changes in surface composition related to the application of AA.

3.3.2 | Cleaning efficacy

Overall, 13 studies could be categorized in this group (Table 3). The publication dates ranged from 1989 to 2018. Seven out of thirteen studies in this group were also presented in Section 3.3.1.[18,41,44,49–52] The included studies reported a significant decrease in surface contamination by abrasive powders. Except for one study,[52] the others reported that glycine powder performed similarly to [49,56] or better than SB.[44] Glycine was more effective than TiO_2 [51] but less effective than calcium carbonate, and a mixtures of glycine and tricalcium phosphate (TCP), erythritol and chlorhexidine, and hydroxyapatite (HA) and TCP.[44,51–53] Total decontamination by AA was shown with SB against *Streptococcus sanguis* on nonmodified (smooth and machined) and modified (structured and rough) surfaces;[54,55] SB and glycine against oral bacterial biofilm on sandblasted and acid-etched (SLA) surfaces;[49] erythritol, HA plus erythritol, and mixture of erythritol and HA with Biomimetic-calcium phosphate (BioCaP) against Ca-precipitated organic film layer on SLA

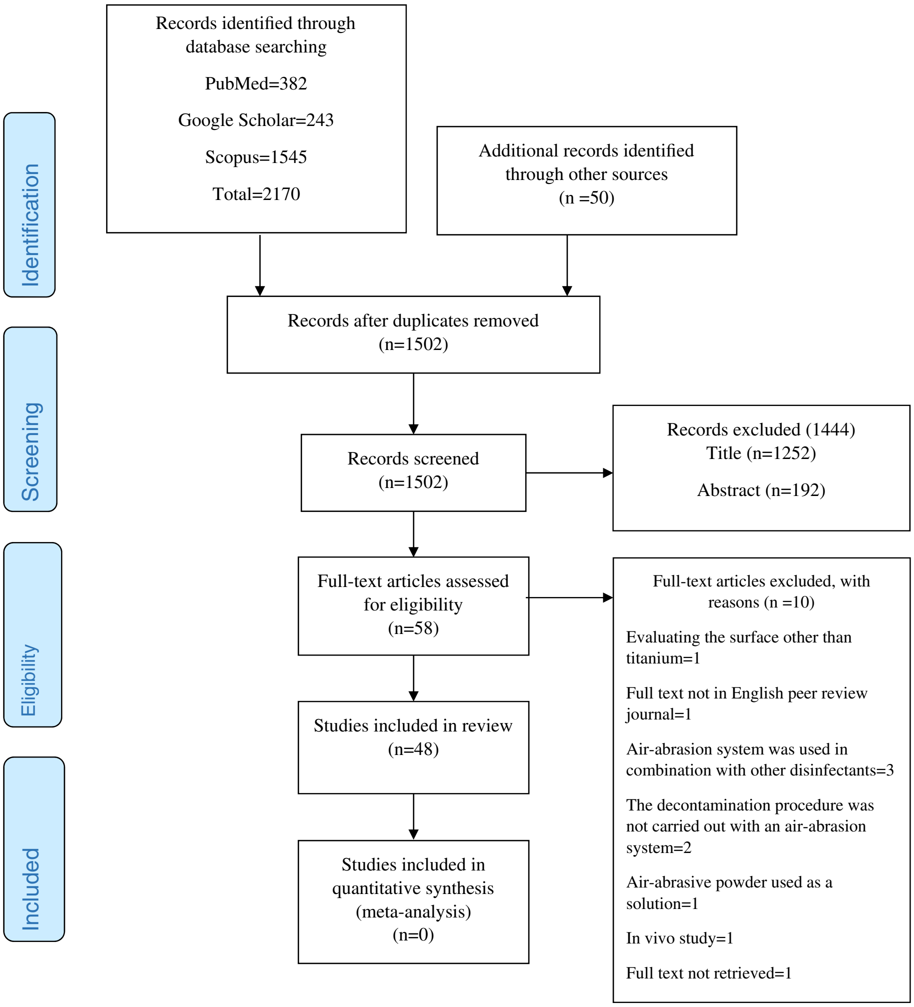

FIGURE 1 Flow chart of the search process

surfaces;[50] and SB against *Actinomyces viscosus* on plasma-sprayed surfaces.[18]

3.3.3 | Biocompatibility

Nine studies were included in this category (Table 4) with the publication dates ranging from 1989 to 2018. Five out of the nine studies in this category also addressed the cleaning efficacy in Section 3.3.2.[18,41,44,49,53] Moreover, five studies which have been presented in Section 3.3.1, also evaluated surface change.[18,41,43–45,49] With regard to the surface, five out of the nine included studies reported that AA either decreased biocompatibility or failed to restore it.[44,45,49,53,59] On the flip side, two studies reported that the vitality [41] and attachment [18] of fibroblasts treated by glycine and SB equaled that of fibroblasts on the untreated clean surfaces. Moreover, surfaces treated with erythritol and osteoinductive powders, such as HA and BioCaP, showed improved cell attachment, viability, and proliferation of osteoblast MC3T3-E1 cells compared to pristine untreated surfaces.[60] Among the powders, two studies reported that glycine performed better than SB regarding cell proliferation[45] and hindering the bacterial colonization,[43] whereas two studies reported that the cell viability of SB was superior to glycine.[44,49]

3.4 | Comparison between air-abrasive and other methods

3.4.1 | Surface change

Twenty-one studies were included in this category (Table 5). The publication dates ranged from 1990 to 2017. Except for one study that compared the AA treatment with just one other decontamination method (Er: YAG laser),[68] other studies compared more than two methods with each other. Out of 21 studies, only 2 studies reported on the surface composition through EDS or X-ray photoelectron spectroscopy (XPS) which found varying levels of sodium (Na) and phosphorus (P) on titanium surfaces after AA.[73,79] These elements were rare in the chemical composition of unused implants and implants treated with other decontamination methods.

Regarding the surface morphology, eight studies reported no or little surface change following application of AA.[20,62,64,67,71,75,76,79] However, 11 studies reported that AA changed the surface profile by causing crater-like defects and scratches or by removing the machine marks on the nonmodified surfaces and by beveling the edges on the modified surface.[61,66,68–70,72–74,77,78,80] Generally, AA resulted in a smoother profile than metal instruments and ultrasonic devices. On the contrary, AA resulted in a similar (most cases) or rougher profile

TABLE 1 Characteristics of the included studies

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
1	Parham et al. (1989) [18]	Implant/ PS	*Actinomyces viscosus*	28	NM	Angle: 90° Distance: 4 mm Time: 5 s	SB	N/A	N/A
2	Rapley et al. (1990) [75]	Abutment/ Nonmodified	N/A	10	CaviJet, Dentsply	Angle: 90° Distance: 5 mm Time: 0.5, 5 s	NM	1. Rotary rubber cup (400 rpm) with and without water and pumice 2. Interdental tapered brush 3. Eva yellow plastic tip on plastic handle 4. Tooth brush 5. Universal plastic scaler 6. Ultrasonic scalar on low setting 7. Stainless steel scaler	1, 6.: 0.5 and 5 s 2, 3, 4, 5, 7:25 and 250 strokes
3	Barnes et al. (1991) [40]	Implants/ 1. Alloyed titanium 2. Pure titanium 3. Highly polished pure titanium 4. Pure titanium with polished collar and PS body	N/A	16	Jet Polisher, Young Dental Mfg	Angle: 90° Distance: 4 mm Time: 0.5, 1, 5, 10 s Pressure: 40 psi	NM	N/A	N/A
4	Zablotsky et al. (1992) [17]	Alloy strips/ 1. Grit blasted 2. HA coated	Endotoxine of *Escherichia coli*	40	NM	Distance: 2–3 mm Time: 30 s	NM	1. Stannous fluoride (1.64%) 2. Chlorhexidine gluconate (0.12%) 3. Tetracycline Hydrochloride (50 mg/mL) 4. Hydrogen peroxide (3%) 5. Chloramine T (1%) 6. Citric acid (pH 1) 7. Plastic sonic scaler	Time: 60 s
5	Homiak et al. (1992) [66]	Abutment/ Nonmodified	N/A	5	CaviJet, Dentsply	Angle: 60° Time: 5 s Distance: 4-5 mm Power: 40-60 mil/min	SB	1. Metal scaler 2. Plastic scaler 3. Rubber cup 4. Rubber cup with tin oxide	1, 2: Moderate finger pressure and three strokes 3, 4: Moderate pressure for 5 s
6	Koka et al. (1992) [46]	Abutments/ Nonmodified	N/A	3	1. ProphyJet, Dentsply 2. Microprophy, Danville Engineering	Angle: 80° Distant: 5 mm Pressure: 70 psi	1. SB+ triCaP 2. SB	N/A	N/A
7	McCollum et al. (1992) [70]	Abutment/ Nonmodified	Oral biofilm	48	NM	Time: 120 s	NM	1. Plastic scaler 2. Rubber cup with pumice	Time: 120 s
8	Dennison et al. (1994) [81]	Press fit cylinders/ 1. None-modified 2. PS 3. HA coated	Endotoxin of *Porphyromons gingivalis*	36	ProphyJet, Dentsply	Time: 60 s	NM	1. Water 2. Citic acid 3. Chlorohexidine	1: Distilled deionized 2: Saturated 3: 0.12%

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
9	Razzoog et al. (1994) [48]	Abutment / Nonmodified	N/A	5	1. ProphyJet, Dentsply 2. Microprophy, Danville Engineering	Time: 60 s Air pressure: 60 and 90 psi	1. SB 2. Aluminum oxide	N/A	N/A
10	Matarasso et al. (1996) [69]	ITI implant neck/ Nonmodified	N/A	50	Air polishing system , Siemens	Distance: 1 or 2 cm Time: 2 s Air Pressure: 5 k/cm^2 Water pressure: 2 k/cm^2 Power: minimum/ maximum	NM	1. Curettes: plastic, titanium and stainless steel (Gracey type 7/8) 2. Ultrasonic scaler with and without plastic tip 3. Rotating instruments: brushes and polishing rubber cups	1: 3 strokes with 300 g pressure 2: 50 g pressure for 2 s 3: 80-130 g pressure, 800 rpm for 5 s
11	Meschenmoser et al. (1996) [72]	Abutment/ Nonmodified	N/A	5	Airflow, EMS	Distance: 4 mm Time: 30 s	SB	1. Titanium curette, 2. Steel curette Nr 14, 3. Plastic curette, 4. Ultrasonic system	1, 2, 3:420 N using 10 strokes 4: NM
12	Brookshire et al. (1997) [62]	Abutment/ 1. Pure titanium 2. Alloyed titanium	N/A	10	ProphyJet, Dentsply	Distance: 4 to 5 mm Time: 25 s Pressure: 55 psi	SB	1. Gold alloy tip scalar 2. High-grade resin scalar 3. Graphite reinforced scaler 4. Rubber cup with tin oxide slurry	1, 2, 3: 25 strokes 4: 25 s
13	Chairay et al. (1997) [42]	Implant (neck and body)/ 1. Nonmodified 2. PS	N/A	8	Satelec F	Time: 5, 15 s Pressure: 52 psi	SB	N/A	N/A
14	Mouhyi et al. (1998) [73]	Branemark titanium implants/ Nonmodified	Failed titanium implants	19	ProphyJet, Dentsply	Time: 30 s	SB	1. Absolute ethanol 2. Ultrasonic with TRI and absolute ethanol 3. Super saturated citric acid 4. CO_2 laser (dry) 5. CO_2 laser (wet)	1:10 min 2:10 min 3:30 s 4, 5: continues mode, 5 W, 10 s
15	Augthem et al. (1998) [61]	Implant/ 1. Nonmodified 2. PS 3. HA coated	Oral biofilm	18	NM	Distance: 5 mm Time: 60 s Pressure: 1.2 bar	SB	1. Plastic curette 2. Diamond curette 5/6 3. Diamond polishing device 4. Ultrasonic Scaler 5. Chlorhexidine 0.1%	Time: 60 s
16	Mengel et al. (1998) [71]	Screw-Vent implant/NM ITI full-screw implant/NM Standard Brånemark implant/NM	N/A	NM	CaviJet, Dentsply	Distance: 2–3 mm Time: 20 seconds Pressure: 3 bar	SB	1. Titanium curette 2. Gracey curette 3. Plastic curette 4. Rubber cup with Zircate prophy paste 5. Ultrasonic scaler with universal insert 6. Densonic sonic scaler with SofTip disposable prophy 7. Densonic sonic scaler with universal tip (Dentsply)	1, 2, 3: five times 4: 20 s, 500 rpm 5: 20 s, 30 000 Hz, 3 bar pressure 6, 7: 20 s, 6300 Hz, 3 bar pressure

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
17	Shibli et al. (2003) [59]	Healing abutment/ Nonmodified	N/A	26	Prophy-Ceramic II, Dabi Atlante	Angle: 45° Time: 30 s	SB	N/A	N/A
18	Kreisler et al. (2005) [68]	Titanium plates/ SLA	*Porphyromonas gingivalis*	48	Airflow, EMS	Time: 60 s	SB	2940 nm Er: YAG laser	Frequency: 10 pps Pulse energy: 60 mJ Application tip: 540 mm Distance: 0.5 mm Water cooling: none Time: 60 s
19	Pereira da Silva et al. (2005) [55]	Titanium sheets/ 1. Nonmodified 2. Aluminum oxide blasted 65 μm 3. Aluminum oxide blasted 250 μm	*Streptococcus sanguinis*	30	NM	Time: 60 s	SB	N/A	N/A
20	Ramaglia et al. (2006) [74]	Cylindrical implants/ 1. HA coated 2. PS	N/A	14	NM	Distance: 5 mm Time: 5 s Pressure: 40 psi	NM	1. Stainless steel curette 2. Plastic curette 3. Ultrasonic scaler	1, 2:300-g force with 4 strokes (5-mm long) 3:50-g force at 5 s
21	Schwarz et al. (2009) [49]	Titanium disks/ SLA	Oral biofilm	160	Air Flow, EMS	Angle: 30 and 90° Distance:1 and 2 mm Time: 20, 40 s Pressure: 4.5 bar, 60 mL water/min	1. Glycine (Soft) 2. Glycien (Perio) 3. Glycine (Clinpro) 4. SB	N/A	N/A
22	Duart et al. (2009) [65]	Titanium disks/ 1. Nonmodified 2. SLA	*Streptococcus Sanguinis*	80	Jet Sonic, Gnatus	Angle: 90^0 Distance: 5 mm Time: 50 s	SB	1. 2940 nm Er: YAG laser 2. Plastic curette 3. Metal curette	1:120 mJ/pulse, angle of 45° under continuous water irrigation 2, 3: Scaled from bottom to top with angle of 70° for 50 s or 30 strokes
23	Schmage et al. (2012) [77]	Titanium disk/ 1. Nonmodified 2. Grit-blasted 3. Acid-etched 4. Acid-etched/grit-blasted	*Streptococcus mutans*	55	Cavitron ProphyJet, Dentsply DeTrey	Angle: 90^0 Distance: 10 mm	Glycine	1. Plastic curette 2. Carbon curette 3. Sonicflex brush 4. Rubber cup 5. Sonicflex implant 6. Piezon master 7. Prophy max 8. Vector system 9. 2940 nm Er: YAG laser	1, 2: Used in scaling mode 3: Without prophylaxis paste; directed perpendicularly onto the experimental surface while moving 4:2500 rpm 5:8000 Hz, 1000 μm amplitude, oscillation in a circle, water cooling 6: 20 000 Hz, 100 μm amplitude, linear oscillation, water cooling 7: 30000 Hz, 200 μm amplitude, linear oscillation, water cooling 8: Used with the Vector fluid polish 9: Distance: 2 mm

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
24	Nemer Vieira et al. (2012) [54]	Pure titanium implant/ 1. Nonmodified 2. Acid etched	*Streptococcus Sanguinis*	20	Profi II Ceramic, Dabi Atlante	Distance: 10 mm Time: 60 s Pressure: 70 (lb/in.)	SB	N/A	N/A
25	Sahrmann et al. (2013) [57]	Implants screw/ Modified rough surface	Indelible ink	18	Airflow Master, EMS	Angle: 90, 60, 30, 15° Distance: 6-8 mm Time: 10 s	Glycine	N/A	N/A
26	Tastepe et al. (2013) [51]	Titanium disks/ SLA	Oral biofilm	36	Air Prophy Unit DP-726, Shanghai Dynamic IndustrymCo.	Angle: 90° Distance: 2 mm Time: 30 s Pressure: 5.5 bar at 60 mL water/min	1. Titanium dioxide 2. Glycine 3. HA sintered 4. CaP	Phosphoric acid (35%)	Time: 30 s
27	Cochis et al. (2013) [43]	Titanium (Grade II titanium disks)/ Nonmodified	Oral biofilm	NM	Airflow Handy, EMS	Angle: 30 and 60° Distance: 5 mm Time: 20 seconds	1. Glycine 2. SB	N/A	N/A
28	Idlibi et al. (2013) [82]	Titanium disks/ Nonmodified	Oral biofilm	200	PROPHYflex 2, KaVo	NM	Glycine	1. 910 nm diode laser 2. Chlorhexidine (0.2%) 3. Cold atmospheric plasma	1:2.5 W, Pulse repetition of 25 ms and a Pause of 50 ms 2:60 s and 200 s 3:3 W or 5 W, line speed of scanning (1 mms^{-1} or 4 mms^{-1}), gas flow (2 L/min)
29	Drago et al. (2014) [53]	Titanium disks/ Sandblasted	*1. Streptococcus aureus* *2. Bacteroides fragilis* *3. Candida albicans*	NM	Airflow, EMS	Angle: 30-60° Distance:20 mm Time: 5 s Pressure: lowest	1. Glycine 2. Erythritol/ chlorohexidine	N/A	N/A
30	Schmage et al. (2014) [83]	Titanium disks/ 1. Nonmodified 2. Acid etched	*Streptococcus mutans*	80	Cavitron ProphyJet, Dentsply DeTrey	Angle: 90° Distance:1 mm Pressure: 0.2 N	Glycine	1. Plastic curette 2. Carbon fiber-reinforced plastic curette 3. Prophylaxis brush 4. Rubber cup 5. Sonic-driven Peek Plastic Tip 6. Ultrasonic Sonic-driven Peek Plastic Tip	1, 2. NM 3. 8000 Hz, 1000 μm amplitude, 60% of power 4. 2500 rpm 5. 60% of power 6. 70% power, 20 000 Hz, 100 μm amplitude
31	Gehrke et al. (2014) [80]	Titanium disks/ 1. Nonmodified 2. SLA	Artificial Calculus	50	UltraJet, Olsen	Angle: 45° Distance: 2-3 mm Time: complete removal of calculus pressure: 80 psi	SB	1. Teflon Gracey Curette (1/2) 2. Titanium Gracey Curette (1/2) 3. Ultrasoni scaler	1. NM 2. NM 3. Angle: 45°
32	Sahrmann et al. (2015) [20]	Dental implant/ 1. Nonmodified (collar) 2. Modified rough surface (body)	Indelible ink	60	Airflow Master, EMS	Time:120 s Defect Angle: 30, 60, 90° Powder: maximum Lavage: maximum	Glycine	1. Gracey steel curette (Nr.11/12) 2. Ultrasonic device with a steel tip	1, 2: defect Angle: 30, 60,90° 1, 2: Time:120 s

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
33	Bennani et al. (2015) [41]	Grade IV pure titanium disks/ Sandblasted with aluminum oxide	*Streptococcus mutans*	55	AIR-N-GO PERIO, Satelec Acteon Group	Angle: 90° Distance: 5 mm Time: 5 s Waterflow: 20 mL/min Pressure:5 bar	Glycine	N/A	N/A
34	Menini et al. (2015) [47]	Healing abutment from grade IV pure titanium/ 1. Nonmodified 2. Acid etched	N/A	4	Turbodent, Mectron	Degree: 60° Distance: 5 mm Time: 5 s (without saliva) Time: 20 s (after exposure to saliva)	1. Glycine 2. SB	N/A	N/A
35	Chen et al. (2016) [64]	Ti-6Al-4 V alloys disks/ 1. Grinded with 1200-grit Silicon carbide 2. Sandblasting with 50 μm aluminum oxide 3. Sandblasting with 100 μm aluminum oxide 4. Sandblasting with 250 μm aluminum oxide 5. SLA	*Escherichia coli*	75	Airflow Master, EMS	Angle: 90° Distance: 10 mm Time: 60 s	Glycine	1. Plastic curette 2. 2940 nm Er: YAG laser	1. 70° contact tip 2. 10 Hz, 100 mJ/pulse (12.7 J/cm^2), 2 mm distance, 90 °
36	Koishi et al. (2016) [45]	Grade II Titanium disks/ Nonmodified	N/A	NM	Handyjet, Morita Ltd.	Time: 60 s	1. SB 2. Glycine (soft) 3. Glycine (perio)	N/A	N/A
37	Toma et al. (2016) [79]	Grade V micro-rough titanium disks/ Sandblasted with aluminum oxide	N/A	NM	Perio-Flow Handy, EMS	1. Noncontact mode 2. Time: 30 s	Glycine	1. Plastic curette 2. Titanium brush 3. Implantoplasty	1: Angle of 70°, 30 s 2. Oscillating at 900/min, 30 s 3. Diamond round-shaped bur on a handpiece working at 26941 RCF, 30 s
38	John et al. (2016) [44]	Titanium disk/ SLA	Oral biofilm	Titanium: 69 Zirconium: 69	Airflow Master, EMS	1. Angle: 90° 2. Distant: 2 mm 3. Time:18 s 4. Water pressure: 4.5 bar 5. Air pressure: 6 bar	1. SB 2. Glycine 3. Glycine + triCaP	N/A	N/A
39	Schmdit et al. (2017) [78]	Titanium screw/ Nonmodified implant neck	*Streptococcus gordonii* (2 h) Mixed bacteria (24 h)	35	Airflow Master, EMS	Time: 30 s	Glycine (perio) Glycine (soft) Erythritol	1. Ultrasonic device (stainless tip) 2. Ultrasonic device (plastic tip) 3. Stainless steel curette 4. Titanium curette 5. Diamond bur and polisher	Time: 30 s

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
40	Cafiero et al. (2017) [63]	Tissue level implants/ Nonmodified collar of implant	N/A	50	Siemens	Distance: 5 mm Time: 10 s Max air pressure: 5 k/cm^2, Max water pressure: 2 kg/cm^2 Pressure: low and high	Glycine	1. Abrasive paste containing zirconium granules in a formaldehyde solution 2. Paste derived from perlite 3. Finishing bur made of composite resin reinforced by zirconia glass fibers 4. Football shaped bur made of composite resin reinforced by zirconia glass fibers	1, 2: Applied with silicone rubber cup or brush mounted on a handpiece set at 800 rpm for 5 s 3, 4: 5 s
41	Kister et al. (2017) [67]	Titanium foils/ 1. Anatase coated 2. Noncoated control	N/A	NM	PROPHYflex 3, KaVo	Distance: 5 mm Time: 20 s	SB	1. Spherical shaped red diamond burs with fine grain of 50 μm 2. Yellow diamond burs with extra fine grain size of 30 μm 3. Pro-Cup rubber cup in combination with a fluoride-free prophy paste 4. Metal curette No 11/12 5. Columbia H6/H7 plastic curette 6. Air Scaler system with a metal tip or a Sonicflex Implant with Plastic PEEK tip	1, 2:10 s, 40.000 rpm with water cooling 3:20 s, 5000 rpm and without water cooling 4, 5:20 times 6:20 s
42	Tastepe et al. (2017) [58]	Titanium disks/ SLA	Biomimetic CaP	48	Airflow Master, EMS	Air pressure:1.7 vs 2.9 bar Water pressure: 0.109 vs 0.512 g/s Nozzle depth: 3 vs 7 mm Powder: Low vs high	Erythritol	N/A	N/A
43	Ronay et al. (2017) [76]	Dental implant/ endosseous Ra: (2.35 ± 0.25 μm)	Indelible ink	180	Airflow Master EMS	Defect Angle: 30, 60, 90° Time: 120 s Powder: maximum Lavage: maximum	Glycine	1. Gracey steel curette (Nr.11/12) 2. Ultrasonic device with a steel tip	1, 2: Defect Angle: 30, 60, 90° 1, 2: Time:120 s
44	Quintero et al. (2017) [56]	Implant/ NM	*Streptococcus sanguinis*	26	1. Cavitron JET Plus, Dentsply Sirona 2. Airflow Perio, EMS	Time: 60 s	1. Glycine 2. SB	N/A	N/A
45	Wei et al. (2017) [52]	Grade IV pure titanium implants/ Sandblast (body)	Indelible ink	3	AIR-N-GO, Satelec Acteon Group	Angle: 30-90° Distance:1-2 mm Time: 120 s Pressure: 25, 35, 45, 55 psi	1. SB 2. Glycine 3. Calcium carbonate	N/A	N/A

(Continues)

TABLE 1 (Continued)

	Author (Year) [Reference]	Titanium component/ surface texture	Contamination method	Number of specimens	Air abrasion device	Settings for air abrasive device	Powder type	Other decontamination methods	Settings for other methods
46	Matthes et al. (2017) [84]	Grade IV titanium disks/ SLA	Oral biofilm	NM	Airflow Master, EMS	Angle:65° Distance: 4 ± 1 mm Time: 90 s Air pressure: 4.75 bar Water pressure: 2.5 bar	Erythritol/ chlorhexidine	Cold atmospheric plasma	Power: 3.5 W Time: 320 s and 720 s Distance: 5 mm
47	Tastepe et al. (2018) [50]	Titanium disks and Implants/ SLA	Ca-precipitate and organic film layer	Discs: 28 Implants: 13	Airflow Master, EMS Airflow Perio, EMS	Angle: 60° Time: 30 s Distance: 4 mm Air pressure: 2.4 bar; Water flow: 42 mL/min	Mixture of 1. Erythritol 2. HA 3. Biomimetic CaP	N/A	N/A
48	Tastepe et al. (2018) [60]	Titanium disks/ SLA	Ca-precipitate and organic film layer	96	Airflow Master, EMS Airflow Perio, EMS	Angle: 60° Distance: 4 mm Time: 60 s Pressure: 2.4 Bar. Water flow: 42 mL/min	Mixture of 1. Erythritol 2. HA 3. Biomimetic CaP	N/A	N/A

Abbreviations: CaP, calcium phosphat; HA, hydroxyapatite; N/A, not applicable; NM, not mentioned; PS, plasma sprayed; SB, sodium bicarbonate; SLA, sandblasted and acid-etched.

than plastic curettes and rubber cups. From the 21 included studies, 7 measured surface roughness quantitatively.[63,65,67,69,72,74,77] All these studies reported on Ra value, but only four studies reported on Rz index.[63,69,74,77] Generally, considering both qualitative and quantitative results, except for four studies which were restrained about using the AA or suggested against its application,[68,69,73,75] other studies found its application superior or at least similar to other decontamination methods with minimum damage to the surface. Compared with the nonmechanical laser decontamination, two studies reported Er: YAG laser [68] and CO_2 laser [73] were superior to AA in terms of keeping the surface intact. However, two other studies reported no distinct advantage of Er: YAG laser over AA,[64,65] and one study even considered AA slightly superior.[77]

3.4.2 | Cleaning efficacy

Eleven studies were included in this category (Table 6). The publication dates ranged from 1992 to 2017. Seven out of the 11 studies in this category were also presented in Section 3.4.1.[20,64,73,76,77,80] Results regarding cleaning efficacy were consistent, and all of the 11 studies reported that AA was superior to other decontamination methods or at least performed similarly to them. Four studies compared nonmechanical laser decontamination with AA and three concluded that AA cleaned better than laser.[73,77,82] Only the study by Chen et al. showed that the cleaning efficacy of Er: YAG laser was similar to AA.[64]

3.4.3 | Biocompatibility

Nine studies were included in this category (Table 7). The publication dates ranged from 1992 to 2017. Seven out of nine studies in this category, which have been presented in Section 3.4.1, also evaluated the surface change,[61,65,67,68,70,78,79] and two studies evaluated cleaning efficacy as well as biocompatibility.[61,82] The bacterial adhesion and colonization were not different between AA and other methods and untreated pristine controls on the nonmodified surfaces,[65,70,78] but on the modified surfaces treated with AA and metal curette bacterial adhesion was lower than the Er: YAG laser and plastic curette.[65] Fibroblast proliferation rate was found to be slightly higher on the SLA surface treated with AA compared with Er: YAG laser [68] and profoundly higher on the nonmodified and plasma-sprayed surfaces compared with plastic curettes.[61] Osteoblast-like cells viability was improved by AA compared with the plastic curette, titanium brush, implantoplasty,[79] and cold atmospheric plasma (CAP).[84] AA with glycine was weaker than CAP and high-density chlorohexidine in preventing regrowth of oral biofilm,[82] but AA with erythritol was superior to CAP.[84]

4 | DISCUSSION

AA is one of the decontamination methods that have demonstrated promising results to treat peri-implant disease.[56,76] AA can have an impact on the implant surface as well as surrounding oral tissues.[21,85,86] Therefore, in the present systematic review, in vitro studies assessing surface changes, cleaning efficacy, and biocompatibility have been analyzed.

TABLE 2 Titanium surface change following air-abrasive decontamination with different settings and powders

	Author (Year) [Reference]	Outcome Measure (Measurement)	Comparison Factor	Results	Conclusion
1	Parham et al. (1989) [18]	Surface morphology (SEM)	Untreated control	Surface smoothness: AA > control	AA resulted in only slight changes on surface morphology such as rounding of angles and edges of the PS coating and occasional surface pitting
2	Barnes et al. (1991) [40]	Surface morphology (SEM)	Untreated control	Surface integrity: AA = control	No perceptible difference was noted between the pretreatment and post-treatment of SEM images of pure, alloyed, PS, and polished titanium surface
3	Koka et al. (1992) [46]	1. Surface morphology (SEM) 2. Surface composition (EDS)	Type of Device	Surface smoothness: ProphyJet > MicroProhpy > control	Both the systems resulted in a smoother surface than control, but the effect of Microprohy compared with ProphyJet was partial and left behind an irregular deposit of sodium.
4	Razzoog et al. (1994) [48]	Surface morphology (SEM)	1. Type of powder 2. Pressure	Surface smoothness: SB > Al_2O_3 60 psi > 90 Psi	Both systems caused insignificant changes to the surface. The phase separation maybe accountable for stronger removal of machine marks by of the lower pressure
5	Chairay et al. (1997) [42]	Surface morphology (SEM)	1. Surface texture 2. Time 3. Neck and body	Surface alteration: Machined>PS 15 s > 5 s Body>Neck	AA modified dental implant surfaces with various effects depending on the settings and specimen material.
6	Schwarz et al. (1998) [49]	Surface morphology (SEM)	1. Powders 2. 1× vs 2× application	Surface smoothness: 2× > 1× SB > ACG	1× application of AA did not alter the surface in any groups. Whereas 2× application using bicarbonate altered the surface, but ACG did not have such an effect.
7	Tastepe et al. (2013) [51]	1. Surface morphology (SEM, Light microscopy) 2. Surface composition (EDS)	Powders	Surface smoothness: No powder = control < TiO_2 < ACG < HA = HA + TCP	AA caused sharp edges around the grooves in the implant surface to be rounded. In the HA and HA + TCP group, a Calcium content was observed varying between 2% and 5%.
8	Cochis et al. (2013) [43]	1. Surface morphology (SEM) 2. Surface topology (Laser profilometry)	Powders	1. Surface smoothness: SB > ACG 2. Ra and Rmax: SB ≃ ACG ≃ control	AA with ACG powder may be considered as a better method than SB for removing plaque from dental implant as it is less aggressive
9	Bennani et al. (2015) [41]	1. Surface morphology (SEM) 2. Surface topology (CLSM) 3. Surface composition (EDS)	Untreated control	1. Surface Smoothness: ACG > untreated 2. Ra: ACG > untreated	The treated surface with AA had a smoother profile (SEM) but at the same time was rougher (Ra). There were no changes in chemical and elemental compositions,
10	Menini et al. (2015) [47]	1. Surface morphology (SEM) 2. Surface composition (EDS)	1. Powder 2. Surface texture 3. Time	Surface alteration: SB = ACG = control 5 s = 20 s Machined = acid-etched	AA for 5 and 20 s with either ACG or SB on machined and acid-etched titanium surfaces did not produce significant surface damage. Acid etched abutments and abutments treated with SB harbored more salts and carbon.
11	John et al. (2016) [44]	1. Surface morphology (SEM) 2. Surface composition (EDS)	Powder	Surface smoothness: SB = ACG = ACG + TCP ≃ control	Discreet flattening of the sharp edges of titanium surfaces was seen in all the groups. Minimal rates of powder remnants were seen

(Continues)

TABLE 2 (Continued)

	Author (Year) [Reference]	Outcome Measure (Measurement)	Comparison Factor	Results	Conclusion
12	Koishi et al. (2016) [45]	1. Surface morphology SEM, SPM 2. Surface topology (SPM)	1. Powder 2. Particle size	1. Surface smoothness: untreated > ACG (25, 65 μm), SB 2. Rz: ACG65 > SB> > ACG25 > untreated Ra: SB > ACG65 > ACG25 > untreated	At high magnification, there were irregularities on the surface. With increasing the particle size, irregularities also increased in size. Ra level correlated with the average particle diameter, but the Rz level did not.
13	Wei et al. (2017) [52]	Surface morphology (SEM, DMC)	1. Powder 2. Air pressure	Surface smoothness: Powders: CC > SB > ACG Pressure:55 > 45 > 35 > 25 psi	Higher air pressure increased surface change except for ACG powder. All powders caused some level of surface alteration, with rounding of surface projections most evident.
14	Tastepe et al. (2018) [50]	1. Surface morphology (SEM, Light microscopy) 2. Surface composition (EDS)	Powder	Surface damage: HA + CaP = Erythritol + CaP = Erythritol = HA = no damage	Powder particles of varying size and shape were embedded on the surface. All HA-or CaP-treated surfaces showed Ca and P content, but no surface damage was reported

Abbreviations: AA, air abrasion; ACG, amino acid glycine; Al_2O_3, aluminum oxide; CaP, calcium phosphate; CC, calcium carbonate; CLSM, confocal laser scanning microscope; DMC, digital macro photograph; EDS, energy dispersive X-Ray spectroscopy; SB, sodium bicarbonate; SEM, scanning electron microscope; SPM, scanning probe microscope; HA, hydroxyapatite; PS, plasma sprayed; TCP, tricalcium phosphate; TiO_2, titanium dioxide.

4.1 | Surface change

When evaluating the efficacy of a decontamination method, it is important to consider that not every surface change is damaging. When defining the surface damage, in general, it is preferable that a decontamination method not change the surface in terms of roughness, free energy, and composition. However, in most cases, the surface change is inevitable. It has been shown that osteoblast-like cells attach more readily to rough surfaces, while epithelial cells and fibroblasts prefer smooth and finely textured surfaces.[87,88] The components, such as abutments, are exposed to the oral cavity and designed to have a smooth surface to inhibit bacterial adhesion and to allow better adaption with the surrounding tissues.[89,90] Thus, it is important that a smooth surface remain intact after decontamination. However, implant surfaces, which are not exposed to the oral cavity and have less chance of being contaminated by bacterial species, undergo modifications by the manufacturer to have a rougher surface which is preferable for osteoblast adhesion.[91,92] That being said, in peri-implantitis, irreversible vertical bone loss occurs which results in exposure of a rough and threaded implant surface to the oral cavity. In such a condition, the removal of the macroscopic and microscopic retentions to reduce microbial adhesion and colonization is suggested for those implant surfaces that remain exposed to the oral environment.[19] However, when the goal is re-osseointegration, the disinfected implants will be submerged, and the bone defects will be augmented. In these cases, preserving the rough surface is needed, therefore, applying an instrument with the least potential for smoothing the surface becomes favorable.[93,94]

Qualitative evaluation is a conventional method for measuring the changes in surface morphology. Most of the included studies in this review used SEM to describe surface morphology. Overall, in nonmodified surfaces, AA with SB removed machined marks and caused small crater defects, but the same effect was not seen with softer powders, such as glycine.[43,65] In modified surfaces, AA slightly beveled the sharp edges and seemed to smoothen the surface. Although SEM results are valuable and may be useful for comparison within a study, they are prone to subjective interpretation and have limitations to indicate the differences between studies.

Atomic force microscopy (AFM), stylus profilometry, and optical profilometry were rarely used to quantify the surface roughness (topology) after AA. Unlike surface morphology which provides a general understanding of the surface profile, surface topology provides information about vertical characteristic and amplitude parameters such as Ra and Rz which can be considered valid indicators of surface roughness.[95] Similar to morphological results,[61,80] the effect of AA on surface topology was partly dependent on the surface textures, that is, the nonmodified and modified surfaces.[65,67,83]

On the nonmodified surface, new generations of AA which were applied for less than 60 seconds and at a distance equal to or more than 5 mm did not significantly alter the surface compared with untreated control.[43,63,65,67,77] One study even reported that high-pressure AA smoothed the surface.[63] The only exception was the study by Koishi et al. which showed AA made the surface rougher after 60 seconds application of AA. The baseline roughness of the surface for this study was 4.7 nm which was smaller than reports of

TABLE 3 Cleaning efficacy of air-abrasive decontamination with different settings and powders for titanium surfaces

	Author (Year) [Reference]	Comparison Factor	Measurement	Results	Conclusion
1	Parham et al. (1989) [18]	Untreated control	SEM	Bacterial removal (%): SB = 100 > control (sterile water) = 75	AA with SB resulted in 100% bacterial removal.
2	Pereira da Silva et al. (2005) [55]	Surface texture	CFU	Residual bacterial cells (CFU): Machined = Grit blasted = 0	With the increase of the surface roughness, an exponential increase in bacterial cells was observed. However, after decontamination, no viable bacteria were detected.
3	Schwarz et al. (2009) [49]	1. Powders 2. 1x vs 2x application	1. SEM 2. Light microscopy 3. Digital camera	Residual biofilm (2x): ACG (Clinpro, Perio, Classic) = SB = 0	Residual biofilm between groups was comparable and both powders resulted in complete decontamination at 2×.
4	Nemar Vieira et al. (2012) [77]	Surface texture	Optical microscopy using Gram staining	Bacterial growth after 48 hours: Machined = Acid-etched = 0	AA with SB removed all the bacterial cells from the tested implants regardless of surface roughness.
5	Sahrmann et al. (2013) [57]	Vertical bone angulation	1. Dye determination 2. Digital images form vertical, 60° and 120°	Uncleaned areas for different bone angulation: 90° (3%) < 60° < (8%) < 30° (24%) < 15° (51%)	Complete surface decontamination could not be achieved in any of the defects. The bigger defects were cleaned more efficiently. Under the threads were cleaned less efficiently than other parts.
6	Tastepe et al. (2013) [51]	Powders	1. SEM 2. Light microscopy	Residual biofilm: HA + TCP < HA < ACG < TiO_2	Reliable cleaning efficacy could be achieved by TCP and HA. Combination of TCP and HA removed 99% of bacteria.
7	Drago et al. (2014) [53]	Powders	1. Spectrophotometric analysis	Reduction of *C.albicans*, *B.fragilis*, and *S.aureus*: Erythritol/CHX > ACG > control	AA with Erythritol/CHX seems to be a viable alternative to the traditional glycine treatment for biofilm removal.
8	Bennani et al. (2015) [41]	Untreated control	1. SEM 2. Crystal violet dye absorbance rate	Residual biofilm: ACG treated < untreated (contaminated)	The amount of biofilm was eight times lower than untreated disks, although some bacteria and polysaccharide remained.
9	John et al. (2016) [44]	Powders	SEM	Residual plaque (%): SB (1.51) > ACG (0.69) > ACG + CP (0.26)	ACG plus CP seemed to be more effective than the control group and both SB and ACG alone.
10	Tastepe et al. (2017) [58]	1. Static vs dynamic movement 2. Pressure 3. Nozzle depth	1. SEM 2. light microscope	Size of the cleaned area: 1. high pressure > low pressure 2. dynamic movement > static 3. deep > superficial	To get the most effective clinical use of AA, it should be applied with high pressure, with deep insertion of the nozzle and enough water flow with the dynamic movement
11	Quintero et al. (2017) [56]	Powders	Spectrophotometer	Residual biofilm (CFU): Untreated (104) >> SB (0.85) ≥ ACG(0.23)	AA was effective for the decontamination. The Cavitron JET Plus (SB) and AIR-FLOW PERIO (ACG) were equally successful at eliminating viable bacteria.
12	Wei et al. (2017) [52]	1. Powders 2. Pressure	Digital macro photograph	Residual ink: CC < SB < ACG 55 < 45 < 35 < 25 psi	No treatment cleaned all the surface of the threads. Higher air pressure improved cleaning efficacy
13	Tastepe et al. (2018) [50]	Powders	Stereo microscope Digital camera	Cleaned surface area: HA + BioCaP = Erythritol+BioCaP= Erythritol = HA = 100% Control = 5%	Osteoinductive treatment with CaP and HA powders under clinically applicable pressure settings gives positive results

Abbreviations: AA, air abrasion; ACG, amino acid glycine; CaP, calcium phosphate; CC, calcium carbonate; CFU, colony forming unit; CHX, chlorhexidine; HA, hydroxyapatite; SEM, scanning electron microscope; SB, sodium bicarbonate; TCP, tri-calcium phosphate; TiO_2, titanium oxide.

TABLE 4 Biocompatibility of titanium surfaces following air-abrasive decontamination with different settings and powders

	Author (Year) [Reference]	Comparison Factor	Measurement	Results	Conclusion
1	Parham et al. (1989) [18]	Untreated control	SEM	Fibroblast attachment: SB = untreated pristine control	Cell attachment did no differ with AA. Fibroblasts exhibited uniform attachment over the entire implant surface
2	Shibli et al. (2003) [59]	Untreated control	SEM	Number of fibroblasts: Untreated control (71.44) > SB (35.31)	No significant differences were found between the groups regarding adhesion, but the number of cells was greater on untreated clean surface.
3	Schwarz et al. (2009) [49]	Powders	1. Digital camera 2. CellTiter-Glo (luminescent assay)	Cell viability of SAOS-2 Clean untreated control > SB > ACG	SB particles resulted in significantly higher mitochondrial activity values than ACG powders of different sizes
4	Cochis et al. (2013) [43]	Powders	SEM	Bacterial colonization (index of density) ACG < Untreated control < SB Bacterial colonization (CFU/ml): ACG < Untreated control = SB	ACG could efficiently hinder colonization of bacterial species on the titanium surface.
5	Drago et al. (2014) [53]	Powders	CFU	Regrowth of *C. albicans*, *B. fragilis*, *S. aureus*: Erythritol/CHX < ACG ≤ contaminated control	Erythritol/CHX was considered to be more effective than ACG for antimicrobial activity
6	Bennani et al. (2015) [41]	ACG and untreated control	1. SEM 2. CLSM	Disc coverage by fibroblast cells (%): Untreated control (41.04) > ACG (20.36) Vitality of cells: Treated = untreated (clean) = 99.6%	Following AA cell viability did not change, but the increased surface roughness appears to have reduced the adhesion and proliferation of the cells on the surface.
7	John et al. (2016) [44]	Powders	CellTiter-Glo (luminescent assay)	SAOS-2 Cell viability (luminescence signal): Clean untreated (9754) > SB (424) > ACG (56) > ACG + TCP (50)	Biocompatibility decreased with AA. The differences between the powders were not significant.
8	Koishi et al. (2016) [45]	1. Powders 2. Particle size	1. Video contact measurement system 2. CellTiter-Blue	Wettability: Untreated < ACG (25 μm) < ACG (65 μm) < SB Proliferation of gingival fibroblasts: Untreated > ACG (25 μm) > ACG (65 μm) > SB	The ACG exhibited higher biocompatibility than the SB, and smaller particles were stronger for decontamination around implants.
9	Tastepe et al. (2018) [60]	1. Powders 2. Pristine and contaminated control	1. SEM 2. AlamarBlue fluorescent assay 3. Cyquant cell proliferation assay	MC3T3-E1Cell attachment (stretchiness): Treated>contaminated (autoclaved)>pristine Cell proliferation (DNA activity): Treated>contaminated (autoclaved)>pristine Cell viability (fluorescent assay): Treated>contaminated (autoclaved)>pristine Differentiation (ALP activity): Pristine > treated > contaminated	There was no difference between HA and Erythritol (coated and noncoated with BioCaP) and both promoted biocompatibility of MC3T3-E1cells. The tested aspects of cell response, except differentiation, reached the level of the pristine surface

Abbreviations: AA, air abrasion; ACG, amino acid glycine; CFU, colony forming unit; CHX, chlorhexidine; CLSM, confocal laser scanning microscopy; SEM, scanning electron microscope; SB, sodium bicarbonate; TCP, tri-calcium phosphate.

TABLE 5 Comparison between air-abrasive decontamination and other methods regarding titanium surface change

	Author (Year) [Reference]	Outcome measure (Measurement)	Measuring factor	Results	Conclusion
1	Rapley et al. (1990) [75]	Surface morphology (SEM)	Ten treatments	Surface smoothness: ultrasonic scale = SS scaler < Control = AA < Rotary rubber cup	The interdental brush, soft nylon toothbrush, plastic scaler, Eva® plastic tip, rubber cup, and AA left surface intact. AA made a negligible corrosive layer with possible surface pitting.
2	Homiak et al. (1992) [66]	Surface morphology (SEM, OM)	Five treatments	Surface smoothness: metal scaler < control < AA, plastic scaler, rubber cup, rubber cup with tin oxide	The rubber cup with tin oxide and AA seemed to produce the most significant polishing effect.
3	McCollum et al. (1992) [70]	Surface morphology (SEM)	Three treatments	Surface Smoothness: AA, plastic scalar, rubber cup> control	All three methods smoothened the surface but with different patterns. AA largely obliterated the milling marks and caused some surface pitting.
4	Matarasso et al. (1996) [69]	1. Surface morphology (SEM, OM) 2. Surface topology (profilometer)	Ten treatments	Ra: ultrasonic scaler, SS curette, titanium curette>AA>control≃rubber cup≃plastic curette>abrasive rubber cup	Surface morphology was not reported for AA. AA system increased surface roughness (Ra:0.8-0.68, Rz:5.33-4.78) compared with the test values (Ra:0.5, Rz:3.98) and did not seem to be appropriate for cleaning.
5	Meschenmoser et al. (1996) [72]	1. Surface morphology (SEM) 2. Surface topology (CLSM)	Five treatments	1. Surface smoothness (SEM): plastic curette = control >titanium curette> AA>Steel curette = ultrasonic scaler 2. Ra: steel curette≃ultrasonic>titanium curette≃ AA≃plastic curette≃control	AA resulted in a small crater-like defects. The titanium curette and AA could only be recommended with restrictions for titanium decontamination.
6	Brookshire et al. (1997) [62]	Surface morphology (SEM)	1. Five treatments 2. Pure and alloyed abutments	Surface damage: control = AA < resin scaler < Rubber cup with tin oxide < graphite and gold scaler Susceptibility to alteration: alloyed titanium < pure titanium	AA was the safest method. Other methods either created significant surface alterations, left residual particles on the abutment surfaces, or both.
7	Mengel et al. (1998) [71]	Surface morphology (SEM, Laser profilometer)	Eight treatments	Surface damage: AA = plastic curette = rubbercup (no damage) < sonic scaler(SofTip) = titanium curette < Gracey curette = Densonic and Cavitron with universal tip	The rubber cup, the plastic curette, and AA caused no visible change to the implant surfaces, and on average removed 0.09 μm substances.
8	Mouhyi et al. (1998) [73]	1. Surface morphology (SEM) 2. Surface composition (XPS)	Six treatments	Titanium percentage on the surface: ethanol < CO_2 laser dry < AA < TRI + ethanol < CO_2 laser wet < ultrasonic cleaning in TRI and ethanol	Comparisons were not possible between groups regarding the morphology. Ten micrometer craters were formed by AA. XPS showed a high level of sodium 38%, oxygen 35%, carbon 16%, and aluminum 1% in AA.
9	Augthen et al. (1998) [61]	Surface morphology (SEM)	1. Five treatment methods 2 Three surface textures	Surface damage (Treatments): CHX < AA = plastic scaler < steel scale < ultrasonic scaler < diamond polishing device Surface damage (Textures): nonmodified < PS < HA coated	AA, CHX, and curettage with a plastic instrument caused little damage in all but the hydroxyapatite-coated fixtures.
10	Kreisler et al. (2005) [68]	Surface morphology (SEM)	Two treatments	Surface damage: control = Er:YAG laser < AA	AA led to microscopically visible alterations of the implant surface whereas laser-treated surfaces remained unchanged.

(Continues)

TABLE 5 (Continued)

	Author (Year) [Reference]	Outcome measure (Measurement)	Measuring factor	Results	Conclusion
11	Ramaglia et al. (2006) [74]	1. Surface morphology (SEM) 2. Surface topology (profilometer)	1. Four treatments 2. PS with HA	Ra (μm) for HA: AA (8.5) > ultrasonic scalar (7.5) > plastic curette (5.8) > SS curette (5.1) > control (4.2) Ra (μm) for PS: control (10.2) > plastic curette (7.7) > AA(6.8) > SS curette (6.5) > ultrasonic scaler (5.7)	PS surfaces were smoothened after decontamination while HA implants became rough. Plastic curette and AA did not damage the coatings like SS curette and air scaler but deposited on the surface (SEM)
12	Duart et al. (2009) [65]	1. Surface morphology (SEM) 2. Surface topology (profilometer)	1. Four treatments 2. Modified and nonmodified	Ra (μm) for nonmodified surface: Er:YAG laser (0.23) $\simeq$ plastic curette (0.24) $\simeq$ AA (0.20) $\simeq$ control < metal curette (0.34) Ra (μm) for modified surface: Er:YAG laser (0.68) $\simeq$ plastic curette(0.70) $\simeq$ AA (0.73) $\simeq$ metal curette(0.69) $\simeq$ control	For the nonmodified surface, the roughest surfaces were produced by metal curette. The modified surface was not altered by any of the treatments
13	Schmage et al. (2012) [77]	1. Surface morphology (SEM) 2. Surface topology (profilometer)	1. Ten treatments 4 Four surface textures	1. Surface damage for AA: acid-etched = SLA = No damage < polished = grit-blasted 2. Ra, Rz in acid-etched, polished, grit-blasted: Ten treatments$\simeq$control 3. Ra, Rz in SLA: Sonic-Flex clean with prophylaxis brush and plastic curette < Satelec ProphyMax	There was an interaction between surface modification and cleaning methods.
14	Gehrke et al. (2014) [80]	Surface morphology (Digital microscope)	1. Four treatments 2. Modified and nonmodified surfaces	Surface change was not reported separately from the cleaning efficacy	For the nonmodified surface, plastic curette was suitable, while for the modified surface, the use of AA resulted in the most effective calculus removal with the least damage.
15	Sahrmann et al. (2015) [20]	Surface morphology (SEM)	Three treatment	Surface smoothness: AA = control < Gracey curette = ultrasonic device	After treatment with glycine powder, surface exhibited no changes except for sporadic glycine particles and grease spot-like surface infiltrations of the titanium both on modified and nonmodified surfaces
16	Chen et al. (2016) [64]	Surface morphology (SEM)	1. Five surface textures 2. Three treatments	Surface damage: ER: YAG laser = plastic curette = AA = control	The use of three cleaning treatments did not induce significant surface alterations in any of the grit blasted, sandblasted, and SLA surfaces.
17	Toma et al. (2016) [79]	1. Surface morphology (SEM) 2. Surface composition (EDS)	Four treatments	Surface smoothness: implantoplasty>Ti-brush>AA = plastic curette = control	AA and plastic curette were the safest methods. Titanium, oxygen, aluminum and carbon were identified as the main components in all disks. sodium, phosphorus, and chlorine were detected in the AA group.
18	Ronay et al. (2017) [76]	Surface morphology (SEM)	1. Three treatments 2. Modified and nonmodified surfaces	Surface smoothness: AA = control < Gracey curette = ultrasonic device	After treatment with glycine powder, surface exhibited no changes
19	Cafiero et al. (2017) [63]	Surface topology (profilometer)	Eight treatments	Ra: low and high-pressure AA < composite resin fibers < burs from composite resins < rubber cup and brush with abrasive pastes	None of the treatments increased implant surface roughness significantly. Treatment with AA at high-pressure resulted in a smoothening of the implant collar surface. Treatment with low-pressure AA kept the surface intact.

(Continues)

TABLE 5 (Continued)

	Author (Year) [Reference]	Outcome measure (Measurement)	Measuring factor	Results	Conclusion
20	Kister et al. (2017)[67]	1. Surface morphology (SEM) 2. Surface topology (profilometer)	1. Ten treatments 2. Anatase-coated surface and control	Ra (titanium): AA≃polishing cup≃Sonicflex Implant≃plastic curette≃control < metal curette < diamond burs Ra (anatase-coated): polishing cup < AA≃Sonicflex Implant≃plastic curette≃control < metal curette < diamond burs	AA was safe for both surfaces. Except for AA, air scalar, and red diamond other interments resulted in different surface in titanium and anatase-coated surface
21	Schmidt et al. (2017)[78]	Surface morphology (SEM)	Eight treatments	Surface smoothness: plastic and SS coated ultrasonic < diamond bur < titanium curette < AA(EP) < AA(SP) = AA (PP) = control < SS curette	Overall, no significant differences were observed in the surface characteristics except for SS Curette based on one-time instrumentation

Abbreviations: AA, air-abrasion; CHX, chlorhexidine; CLSM, confocal laser-scanning microscope; EDS, energy dispersive X-ray spectrometry; EP, Erythritol Perio; HA, hydroxyapatite; OM, optical microscope; PP, Perio powder (glycine 25 μm); PS, plasma sprayed; SEM, scanning electron microscope; SS, stainless steel; SP, Soft Perio (glycine 65 μm); TRI, trichloroethylene; XPS, X-ray photoelectron spectroscope.

other studies where the baseline roughness was around 200 nm, and this difference can be accounted for the sensitivity of the surface which illustrated the changes more evidently.[45] Among the powders, harder ones such as SB (Mohs hardness scale: 2.5, density:2.16 g/cm^3) imposed more damage than softer and smaller powders like glycine (Mohs hardness scale: 2, density: 1.61 g/cm^3).[43,45]

On the modified surface, an interaction between the type of modification and decontamination methods on surface roughness was reported.[74,77] AA kept anatase-coated,[67] acid-etched,[77] grit-blasted,[77] and SLA [65,77] surfaces almost intact, but smoothed plasma-sprayed surfaces and roughened HA [74] and aluminum oxide blasted surfaces.[41]

In addition to the effect of the type of powder and baseline surface texture, other parameters were also important on the degree of surface change. Higher air pressure,[48,52,58,63] bigger particle size,[45,49,78] and longer application time [40,42,49,75] could intensify the surface change. Nevertheless, with a moderate setting, surface damage caused by AA was comparable to plastic tipped instruments, polishing cups, and Er: YAG laser, but less than metal instruments and ultrasonic devices.

4.2 | Cleaning efficacy

Depending on the moderating effect of the type and size of the powders, device settings, surface texture, and contamination protocols, AA resulted in a range of cleanliness. Also, it seems there is a trade-off between the cleaning efficacy and surface change.[52] Therefore, finding a decontamination method with the highest cleaning efficacy and the least surface damage, which can also maintain the surface biocompatibility or improve it, is favorable.

There was no clear-cut difference between the cleaning efficacy of SB and glycine, and the results seemed to be mostly dependent on the interaction between type of the powder and the type of contamination, surface modification, AA settings, and particle size. That being said, SB in higher pressure and longer duration was more successful than glycine in cleaning the artificial contamination but posed more damage as well [52]. However, in surfaces contaminated by bacterial biofilm which was abraded for 60 seconds and less, glycine was as effective as SB [49,56] or even more successful.[44] Calcium carbonate showed both higher cleaning efficacy and surface damage compared with SB and glycine probably due to the higher hardness (Mohs hardness scale: 3).[52] Similarly, Tastepe et al. showed that HA (5-35 μm) and HA plus TCP made the surface cleaner than glycine but caused more damage due to being harder.[51] However, in a later investigation, smaller particles of HA (5 μm) and Bio-CaP in the mixture with erythritol compensated the hardness problem of the particles. Therefore, the surface was kept intact and complete decontamination was achieved.[50] Overall, compared with other powders, glycine seemed to be safer for the surface, but at the same time, it had slightly less cleaning potential.

AA performed significantly better than other instruments, particularly in the modified and threaded surface where the accessibility of the mechanical instruments was limited. Only the cleaning efficacy of Sonic-Flex Clean with proxy brush equaled the AA in modified surfaces, but this method damaged the surface more than AA.[77] Moreover, instruments, such as a plastic curette, which was as safe as AA could not achieve adequate cleaning.[64,77,83] Among nonmechanical instrument, ER: YAG laser resulted in a less cleaning and higher

TABLE 6 Comparison between cleaning efficacy of air-abrasive decontamination and other methods on titanium surfaces

	Author (Year) [Reference]	Comparison factor	Measurement	Results	Conclusion
1	Zablotsky et al. (1992) [17]	Eight treatments and two controls	Radioactivity	Remaining endotoxin (LPS): AA < plastic sonic scaler < CA < chloramine T < burnished control < hydrogen peroxide < Tetracycline HCL < CHX < untreated control < Stannous fluoride	AA was significantly more successful than other decontamination methods.
2	Dennison et al. (1994) [81]	1. Four treatments 2. Three surface textures	Radioactivity	Reaming endotoxin (I-LPS): Nonmodified: AA = CHX = water < CA PS: AA < CHX = CA = water HA: AA = CA < water < CHX	AA was the most effective method with reducing the level of radioactivity 98.5% for machined implants, 84.2% for PS implants, and 88.8% for HA-coated implants.
3	Mouhyi et al. (1998) [73]	Six treatments	SEM	Cleaned surface: Ethanol, CO_2 laser (dry) < CO_2 laser (wet) < TRI and ethanol < ultrasonic with TRI < citric acid, AA	Cleaning with AA and citric acid following 5 min of rinsing were efficient and resulted in a clean surface.
4	Augthun et al. (1998) [61]	1. Three treatments 2. PS and nonmodified	SEM	Biofilm removal: Nonmodified: AA > plastic curette > CHX (0.1%) PS: AA > plastic curette > CHX (0.1%)	Cleaning efficacy of the AA was superior to other methods with the lease surface damage
5	Schmage et al. (2012) [77]	1. Ten treatments 2. Four surface textures	SEM	Biofilm removal: Sonic-Flex Clean implant set and AA > Er: YAG laser > rubber cup > carbon curette, plastic curette	AA and Sonic-Flex Clean Implant set were the most effective methods and completely cleaned polished, acid-etched, and SLA surface. No method could clean the blasted surface completely
6	Idlibi et al. (2013) [82]	Four treatments	1. Protein content of biofilm 2. SEM	The quantity of biofilm: AA < diode laser < CAP < CHX 60s $\simeq$ CHX 200 seconds	Regarding the quantity of biofilm, AA had the best results. However, no single method achieved complete biofilm removal
7	Schmage et al. (2014) [83]	1. Seven treatments 2. Modified and nonmodified	Light microscopy	Remaining biofilm (Acid-etched): AA, Sonic and ultrasonic PEEK < prophylaxis brush < rubber cup < plastic curette, CFRP curette Remaining biofilm (Polished): AA, Sonic and ultrasonic PEEK, prophylaxis brush, rubber cup < plastic and CFRP curette	AA and oscillating PEEK plastic tips resulted in less than 4% of biofilm in both acid etched and polished surfaces.
8	Gehrke et al. (2014) [80]	1. Four treatments 2. Modified and nonmodified	Digital microscope	machined cleaned area (%): AA (94.4) > ultrasonic (91.8) > Teflon curette (90.3) > metal curette (76.9) SLA cleaned area (%): AA (100.0) > ultrasonic (91.4) > metal curette (71.6) > Teflon curette (25.7)	The calculus deposits on the machined surfaces were more effectively removed with all methods when compared to the rough surfaces. AA method was more efficient compared with other groups on both surfaces.
9	Sahrmann et al. (2015) [20]	Three treatment	SEM	Remaining Ink (%): Gracey curette (24.1) > ultrasonic (18.5) > AA (11.3)	AA using glycine powders seems to constitute an effective therapeutic option for the debridement of implants in peri-implantitis defects.
10	Chen et al. (2016) [64]	1. Three treatments 2. Five surface textures	1. SEM 2. alamarBlue assay	*Escherichia Coli* reduction: ER; YAG laser = AA > plastic curette	AA and Er:YAG laser were more successful in cleaning than plastic curette in grit-blasted, SLA, and sandblasted surfaces.
11	Ronay et al. (2017) [76]	Three treatment	SEM	Remaining Ink (%): Gracey curette (74.70) > ultrasonic (66.95) > AA (33.87)	Although no method achieved complete decontamination, AA showed a superior cleaning potential for all defect angulations with better results at wide defects

Abbreviations: AA, air abrasion; SEM, scanning electron microscope; CA, citric acid; CAP, cold atmospheric plasma; PS, plasma sprayed; CFRP, carbon fiber-reinforced curette; CHX, chlorohexidine; HA, hydroxyapatite; PEEK, polyether ether keton; TRI, trichloroethylene.

TABLE 7 Comparison between air-abrasive decontamination and other methods regarding biocompatibility of titanium surfaces

	Author (Year) [Reference]	Comparison factor	Measurement	Results	Conclusion
1	McCollum (1992) [70]	Three treatments	SEM	Bacterial colonization: Control = AA = plastic rubber cup = plastic curette	The percentage of surface covered by oral biofilm was not different between the decontamination methods and control
2	Augthun et al. (1998) [61]	1. Two treatments 2. PS and nonmodified	1. SEM 2. Live/dead staining 3. Flurescence microscope	Fibroblast vitality (24 h): PS: AA≃control > plastic curette Nonmodified: AA≃control > plastic curette	AA completely removed the oral biform, and therefore could reestablish biocompatibility
3	Kreisler et al. (2005) [68]	1. Two treatments and two control groups	1. SEM 2. Redox indicator (Alamar Blues Assay)	Fibroblast proliferation (48 and 72 h): AA≃sterile disks≃ER:YAG laser > contaminated untreated disks	AA and Er: YAG laser treated surfaces caused cell growth similar to the sterile specimens.
4	Duart et al. (2009) [65]	1. Four treatments 2. Modified vs nonmodified surface	1. SEM 2. CFU	Bacterial adhesion: Modified surface: Control, Er:YAG laser > plastic curette > metal curette = AA Nonmodified surface: Control = Er: YAG laser = plastic curette = metal curette = AA	There was no difference between all the methods on the nonmodified surface. On modified surface, AA and metal curettes were more successful than others.
5	Idlibi et al. (2013) [82]	Four treatments	1. SEM 2. Dead/live cell staining 3. Colony formation on Agar	Bacterial growth on agar: CAP < CHX(200 s) < AA < diode laser < CHX(60 s) Fluorescence coverage: diode laser < CHX(200 s) < CHX(60 s) < CAP < AA	Regarding controlling the viability of the biofilm after decontamination, cold plasma and high-density CHX performed better than AA.
6	Toma et al. (2016) [79]	Four treatments	1. SEM 2. WST-1 kit 3. ALP activity	Contact angle: plastic curette > control = AA = Ti-brush > implantoplasty SAOS-2 proliferation (day 6) control = plastic curette < implantoplasty, Ti-brush < AA	Viability was similar in all groups but significantly higher in the AA than the control group at day 6. ALP, OPG, and OCN protein expression at day 7 was similar in all groups.
7	Schmidt et al. (2017) [78]	Eight treatments	1. SEM 2. Number of colonies	Bacterial colonization: Plastic and stainless steel coated ultrasonic = diamond bur = Ti curette = AA glycine (Perio and Soft) = AA erythritol = stainless steel curette = control	No significant differences were evident between instrumented or control surfaces in 2 h and 24 h after bacterial cultivation.
8	Kister et al. (2017) [67]	1. Ten treatments 2. Anatase-coated surface vs control	DSA	Contact Angle (uncoated titanium): Metal curette < AA≃Sonicflex Implant≃plastic curette < polishing cup < control < yellow diamond burs Contact Angle (anatase-coated): AA < control < other methods	AA improved wettability on the titanium and anatase coated surfaces
9	Matthes et al. (2017) [84]	Three treatments	SEM	MG-63 cell coverage: AA > clean control > AA + CAP > CAP = 0 Biofilm coverage: CAP = contaminated control > AA = AA + CAP = 0 Contact Angle: AA+CAP = 0° < AA < CAP < control	AA with erythritol alone was more efficient than CAP and combination of AA and CAP in restoring the biocompatibility

Abbreviations: AA, air abrasion; CAP, cold atmospheric plasma; CFU, colony forming unit; CHX, chlorhexidine; DSA, drop shape analysis system; SEM, scanning electronic microscope; PS, plasma sprayed.

surface damage [77] or similar cleaning and surface damage [64] compared with AA. The inconsistency between these two studies may be attributed to the differences in powder size (63 μm vs 25 μm glycine), different contaminants (*Streptococcus mutans* vs *Escherichia coli*), and surface texture. Older generations of lasers such as CO_2 resulted in less cleaning, but less surface damage compared with older generations of AA with SB.[73]

4.3 | Biocompatibility

Regarding the wettability, AA could preserve or improve the surface wettability regardless of the surface texture.[45,67,79,84] The high wettability of the surface is mainly determined by its composition, such as the concentration of the carbon. The lower rate of carbon leads to higher wettability and in turn higher bone response and acceptable osseointegration.[96] Regarding the cell and bacterial viability and activity, the effect of AA was mostly dependent on whether the surface was contaminated or not.

4.3.1 | Noncontaminated surfaces

Bacterial colonization did not increase following AA on the nonmodified surfaces [43,65,70,78] probably because the surface profile was preserved and roughness of the 0.2 μm of the nonmodified surface, below which bacterial species cannot adhere to the surface,[97] was not changed following AA. Hindering the bacterial colonization was better done with glycine which was less aggressive [43] and assumed to have an antiseptic effect.[98] Interestingly, on the modified surface, AA and metal curettes hindered bacterial colonization better than control and other plastic instruments probably due to flattening the edges and presence of the powder remnants which could inhibit bacterial adhesion.[65]

AA with glycine resulted in higher osteoblast-like cells proliferation than the untreated control [79] as it probably made the surface rougher which is suitable for osteoblast adhesion.[99] On the contrary, AA resulted in lower fibroblast cell proliferation than the untreated control.[41,45,59] It seems that keeping the wettability alone intact does not ensure fibroblast proliferation. The SB reduced the fibroblast proliferation more than glycine [45] probably because it damaged the surface more severely; it was found that smoother surfaces are superior in promoting fibroblast proliferation.[88] Moreover, since attachment and spreading of the cells depend on the surface chemistry as well as surface structure,[100] the fewer number of fibroblasts after AA can also be attributed to the powder remnants and releasing of the surface ions.[101] That being said, unlike cell proliferation, the cell attachment for fibroblast treated with SB [18] and cell vitality for those treated with glycine [41] remained similar to the controls despite the surface damage.

4.3.2 | Contaminated surfaces

Regarding the contaminated surfaces, the two studies that evaluated the bacterial regrowth rate after decontamination showed that although AA with glycine significantly cleaned surface, it could not decrease the viability and activity of the remaining bacteria.[53,82] This denotes that the antiseptic effect of glycine may not be detrimental against the polymicrobial biofilm. However, a combination of chlorhexidine, which is a broad-spectrum antimicrobial agent, and erythritol, which has antibiofilm activity, yielded promising results and was more effective than glycine.[53,84]

Glycine and SB resulted in osteoblast-like cells viability less than pristine controls.[44,49] Failure of AA to restore cell viability in in-vivo-like conditions could be due to the changes in the composition of titanium and surface oxide layer. Nevertheless, SB was more effective than glycine in restoring biocompatibility probably due to its harder and bigger particles which caused stronger ablation which in turn removed more of the carbon layer produced by biofilm activity. The excessive carbon layer has a negative impact on the surface free energy and hinders cell attachment and activity.[102] Interestingly, AA with hard particles such as HA and BioCaP could improve the cell viability and proliferation of osteoblast-like cells.[60] These osteoconductive particles may have compensated the adverse effects of endotoxin and previous contamination. AA with erythritol also improved osteoblast-like cell proliferation [60,84] probably due to improved cell spreading.[103] For the fibroblast cells, the one study that evaluated cell proliferation showed that cell viability on pristine samples equaled those following AA with SB. Besides the ablation potential of SB, this result can be due to the fact that this study used one bacterial species (*Porphyromonas gingivalis*) instead of complex biofilm.[68] Moreover, fibroblast vitality on the treaded implants following AA remained the same as untreated clean samples.[61]

5 | LIMITATIONS AND SUGGESTIONS FOR FUTURE STUDIES

The results of this review should be interpreted within some limitations. First, some important moderating factors, such as the titanium surface texture (nonmodified vs modified), size of powder particles, air pressure, and application time, which can change the nature of the AA efficacy, should be considered when choosing AA for decontamination. More studies should be conducted to measure the role of moderating factors. Second, it is important that future studies focus more on quantitative reports, at least on the surface roughness to ease the comparison between different methods. Third, surface change, cleaning efficacy, and biocompatibility should be investigated in a single approach to provide a comprehensive picture of the efficacy of AA. Fourth, due to the limitations regarding space and accessibility in the nonsurgical approach, AA may result in less cleaning efficacy, but also less surface damage in the oral cavity where the accessibility is limited; most of the studies used AA at a 90° angle, which cannot be applied in nonsurgical clinical settings. The accessibility is a problem, particularly when treating lower aspects of the threads in narrow defects. In such cases, specific AA units, such as Air Flow Perio, may perform better than others in the in vivo condition due to their tip design providing better adaptability and supporting tridirectional spray.[56] However, if the approach to the sub-gingival defects is strictly restricted, the surgical approach is recommended to provide more convenient access. Fifth, not all the outcome measures that determine the efficacy of AA could be summarized. In the clinical settings, AA may cause irritation and epithelial desquamation, and there is also a chance for the occurrence of emphysema.[104,105] Additionally, some studies included in this review found residual powders and some level of alterations in surface compositions [44,51,60,65] which, depending on nature, may impede the tissue healing.

6 | CONCLUSIONS

(a) According to the SEM results, except for mild crater-like defects by hard powders, AA did not cause a substantial morphological change in nonmodified surfaces. In modified surfaces, decontamination with AA beveled sharp edges but did not alter the surface morphology significantly. The results of surface roughness (Ra values) showed that AA did not roughen nonmodified surfaces; modified surfaces were smoothed, roughened, or remained intact depending on the interaction between the AA and surface modification. Overall, AA showed acceptable surface alteration in the range seen with plastic curettes and Er: YAG lasers for both nonmodified and modified surfaces. SB was little more aggressive than glycine, but both powders resulted in an acceptable surface change. (b) AA showed significant cleaning efficacy, which was superior or equal to all other decontamination methods. No decontamination method surpassed the cleaning efficacy of AA. These results were pertinent for both older types of implants such as machined, plasma spray-coated, and HA-coated or new generations such as SLA and nano-coated surfaces. All types of powders including glycine, SB, erythritol, HA, and CaP were significantly successful for decontamination and depending on other moderating factors could achieve 100% cleaning. Nevertheless, the cleaning efficacy of calcium carbonate, erythritol/chlorhexidine, and HA with or without TCP was more prominent. (c) The main drawback of the AA method seems to be its limitation in restoring the biocompatibility. However, AA itself was not meaningfully detrimental to the surface. It seemed that the effect of contamination and bacterial endotoxin, which altered the surface chemistry, played a significant role in reducing biocompatibility. AA was more successful to preserve biocompatibility for noncontaminated than contaminated surfaces. For the contaminated surfaces, the best results obtained using erythritol/chlorhexidine which even surpassed the efficacy of CAP. Compared with other decontaminants, AA was more efficient than most traditional mechanical instruments and Er: YAG laser.

CONFLICT OF INTEREST

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

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