Air Powder Abrasive Treatment as an Implant Surface Cleaning Method: A Literature Review

Ceylin S. Tastepe, DDS¹/Rien van Waas, DDS, PhD²/Yuelian Liu, DDS, PhD³/Daniel Wismeijer, DDS, PhD²

Objective: To evaluate the air powder abrasive treatment as an implant surface cleaning method for peri-implantitis based on the existing literature. **Materials and Methods:** A PubMed search was conducted to find articles that reported on air powder abrasive treatment as an implant surface cleaning method for peri-implantitis. The studies evaluated cleaning efficiency and surface change as a result of the method. Furthermore, cell response toward the air powder abrasive-treated discs, reosseointegration, and clinical outcome after treatment is also reported. **Results:** The PubMed search resulted in 27 articles meeting the inclusion criteria. In vitro cleaning efficiency of the method is reported to be high. The method resulted in minor surface changes on titanium specimens. Although the air powder abrasive-treated specimens showed sufficient levels of cell attachment and cell viability, the cell response decreased compared with sterile discs. Considerable reosseointegration between 39% and 46% and improved clinical parameters were reported after treatment when applied in combination with surgical treatment. The results of the treatment are influenced by the powder type used, the application time, and whether powder was applied surgically or nonsurgically. **Conclusion:** The in vivo data on air powder abrasive treatment as an implant surface cleaning method is not sufficient to draw definitive conclusions. However, in vitro results allow the clinician to consider the method as a promising option for implant surface cleaning in peri-implantitis treatment. Int J Oral Maxillofac Implants 2012;27:1461–1473

Key words: airflow, biofilm, implant surface, peri-implantitis

Peri-implantitis is an inflammatory process around an implant, characterized by soft tissue inflammation and loss of supporting marginal bone. It has been associated with a predominantly gram-negative anaerobic microflora. The microflora associated with peri-implantitis is similar to that associated with peri-odontal disease. Opportunistic periodontal pathogens such as Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, Bacteroides forsythus, Prevotella intermedia, Peptostreptococcus micros, and Fusobacterium nucleatum have been identified in association with peri-implantitis in partially edentulous patients. 3,4

Correspondence to: Dr Daniel Wismeijer, Academic Centre for Dentistry Amsterdam (ACTA), Gustav Mahlerlaan 3004, 1081 LA Amsterdam, The Netherlands. Fax: +31-(0)20-5980333. Email: D.Wismeijer@acta.nl

Few studies provide data on the prevalence of periimplant diseases. Two studies reported the prevalence of peri-implantitis as 28% in at least 56% of subjects, and in 12% and 43% of implant sites. However, general studies report percentages between 5% and 10%. 5-7

Several attempts have been made to find the optimum treatment for peri-implantitis. Treatment has to consist of the elimination of the infection and restoration of the original peri-implant condition, ie, to create conditions favorable to reosseointegration on the exposed implant surface. Reosseointegration is described as formation of new bone onto a previously biofilm-contaminated implant surface.⁸

Noninvasive (using antimicrobial and anti-inflammatory medicine), resective (removing the granulation tissue and decontaminating the implant surface), and regenerative (restoring the bone defect) treatments have been described in conjunction with various methods of additional surface cleaning and decontamination by chemical agents, mechanical devices, or laser applications or ultraviolet (UV) irradiation.^{9–13}

The air powder abrasive treatment is one of the mechanical methods described in the literature. It uses an abrasive powder brought into a stream of compressed air to clean or polish all kinds of surfaces by removing deposits or smoothing its texture. ¹⁴ The air powder abrasive devices with different types of powders are commonly used for supra- and subgingival biofilm

The International Journal of Oral & Maxillofacial Implants 1461

¹Researcher, Department of Oral Implantology and Prosthetic Dentistry, Academic Centre for Dentistry Amsterdam (ACTA), Research Institute MOVE, VU University and University of Amsterdam, Amsterdam, The Netherlands.

²Professor, Department of Oral Implantology and Prosthetic Dentistry, Academic Centre for Dentistry Amsterdam (ACTA), Research Institute MOVE, VU University and University of Amsterdam, Amsterdam, The Netherlands.

³Assistant Professor, Department of Oral Implantology and Prosthetic Dentistry, Academic Centre for Dentistry Amsterdam (ACTA), Research Institute MOVE, VU University and University of Amsterdam, Amsterdam, The Netherlands.

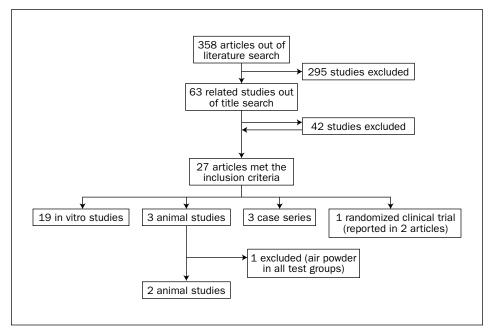


Fig 1 Flowchart of the selection of studies for review.

removal on teeth.¹⁵ Additionally, the same method is reportedly used for implant surface cleaning in combination with peri-implantitis treatment.

The aim of this review is to evaluate the air powder abrasive treatment as an implant surface cleaning method for peri-implantitis treatment with respect to the cleaning efficiency, the influence on the implant surface, and the clinical response, and to answer the question of whether it is possible to achieve reosseointegration following the treatment.

MATERIALS AND METHODS

A literature search was carried out in PubMed using the following key words: Air powder abrasive OR Air polish* OR Mechanical cleaning implant OR Perimplantitis air powder OR Peri-implantitis air powder abrasive OR implant surface air powder OR air abrasive OR air abrasive implant OR air abrasive implant surface OR air abrasive peri implantitis OR peri implantitis decontamination OR re osseointegration peri implantitis surface OR peri implantitis surface modification. The database was searched for studies conducted in the period from 1955 until May 2011.

The inclusion criteria were: (1) articles in the English language; (2) articles that reported on the effect of air powder abrasive treatment on titanium implants, titanium abutments, titanium discs, or titanium platelets; (3) and in vitro, animal as well as human, studies.

The search resulted in 358 articles. After reviewing the titles and authors, 295 articles were excluded since they did not report on the effect of air powder abrasive treatment on titanium implants, discs, or abutments. Articles that could be related to the subject (63) were checked again through their abstracts and 36 of them did not meet the inclusion criteria; therefore, 27 articles were selected for review.

Among these 27 articles, 19 were in vitro studies, 3 were animal studies, 3 were case series, and 1 was a randomized clinical trial (reported in two articles). In one of the three animal studies, air powder abrasive treatment was used as a debridement method for all groups and the regenerative procedure was changed; therefore, this study was excluded for not exclusively reporting on the outcome of the air powder abrasive treatment.

In addition to these articles, six related studies were found during a manual search. However, all of these studies used air abrasive treatment as a standard debridement method to change the regenerative procedures in the test groups. The results do not report specifically on air powder abrasive treatment; therefore, these studies were not included.

The search of the database was performed independently by three different reviewers (CST, YL, and DW), first by title and abstract. In a second step, the full texts of the articles were read and papers fulfilling the inclusion criteria were chosen. Disagreements were resolved by discussion. All three reviewers agreed on the final articles selected (Fig 1).

The 27 remaining studies showed a variety in study design, application period, specimen type (implants, abutments, discs, platelets), and evaluation method (microbiologic, histologic, electron microscopy). They also differed in (1) treatment method (invasive or noninvasive); (2) powder types (sodium bicarbonate, amino acid glycine); (3) specimen types (implants [machined, TPS, HA, SAE implants], titanium discs, titanium abutments); (4) evaluation method (clinical, radiologic, histologic, microbiologic); and (5) evaluated aspects (cleaning efficiency, surface changes of the titanium, cell response).

Therefore, the studies were classified regarding the different aspects of the outcome of the air powder treatment on titanium specimens. Each aspect of the treatment is presented in tables under subtitles and the results were compared and analyzed. Since there was such broad variability among studies, a meta-analysis was not possible.

The studies were classified into five groups and presented separately in tables for each group. In presenting the results of the studies, only the information regarding the subject of the table is presented. Additional results on treatments other than air powder abrasive are not included in the tables.

Group Classification

Group 1: Cleaning Efficiency. In these studies, the cleaning efficiency of air powder abrasive treatment was evaluated with contaminated titanium implants, abutments, disks, or platelets. The specimens were contaminated with either bacteria endotoxin or biofilm and cleaned by air powder abrasive treatment afterwards. The residual bacteria or endotoxin were measured microbiologically and residual biofilm areas were measured by microscope.

Group 2: Surface Change. The surface of the titanium specimen before and after air powder abrasive application was monitored by scanning electron microscope. The change caused by the application was evaluated.

Group 3: Cell Response. Titanium surfaces were tested before and after air powder abrasive treatment in cell cultures to evaluate the osteoblast or fibroblast response to these surfaces. Cell attachment, proliferation, DNA activity, and cell viability were tested.

Group 4: Reosseointegration. These studies measured reosseointegration histologically or radiologically following air powder abrasive treatment on infected implants.

Group 5: Clinical Outcome. Clinical parameters like bleeding on probing, suppuration, and probing depth were measured in peri-implantitis patients who underwent air powder abrasive implant surface cleaning treatment.

RESULTS

Cleaning Efficiency

The cleaning efficiency of air powder abrasive treatment was evaluated by seven studies (six in vitro and one randomized clinical trial)^{16–22} (Table 1).

Two in vitro studies tested the removal of bacterial endotoxin from titanium specimens by several methods. Zablotsky et al¹⁶ reported significantly greater amounts of bacterial endotoxin removal with air powder abrasive treatment than citric acid, stannous floride, tetracycline HCl, chlorhexidine gluconate, hydrogen peroxide, chloramine T, sterile water, or a plastic sonic scaler tip. Dennison et al¹⁸ reported bacterial endotoxin removal at 98.8% from machined titanium surfaces, 84.2% from plasma sprayed surfaces, and 88.8% from HA-coated surfaces using air powder abrasive treatment. Three studies tested the removal of bacteria instead of endotoxin and all three reported 100% removal of the bacteria. 18-20 Mouhyi et al²¹ applied air powder abrasive treatment to failed implants and reported efficient cleaning that resulted in a clean surface as observed by SEM.

A randomized clinical trial on this subject²² compared Er:YAG laser and air powder abrasive treatment by nonsurgical treatment. A total of 74 bacterial species were checked by pre- and posttreatment microbiologic samples. Although Pseudomonas aeruginosa, Staphylococcus aureus, and Staphylococcus anaerobius were found at lower counts after 1 month, the treatment failed to reduce the bacterial counts at 6 months; however, this was a nonsurgical treatment based on studies included in the Consensus Report of the Sixth European Workshop on Periodontology. This conference concluded that nonsurgical therapy on periimplantitis lesions is not effective. Additionally, to the authors' knowledge, no study reporting on the outcome of open surgical debridement with air powder treatment has been published.

According to these studies, in vitro cleaning efficiency of air powder abrasive treatment on titanium strips, disks, or implants is high. However, this result is not supported by the only clinical study that tested the method in a nonsurgical setup.³⁸ More clinical studies are needed to surgically test the treatment on implant surfaces.

Surface Change

Sixteen in vitro studies reported on the surface change of titanium implants, abutments, or disks following the air powder abrasive treatment^{17,19–21,23–34} (Table 2). Eight studies used titanium implants, four studies used titanium abutments, one study used both implants and abutments, one study used titanium platelets, and two studies used titanium disks. The application time, as well as the specimen types, differed among the studies.

Table 1	Studies	Evaluating	the Cleaning Effic	ciency of Air Powder Abrasive Treatment
Study (y)	Туре	No. of specimens	Implant type	Decontamination method
Parham et al ¹⁷ (1989)	In vitro	28 implants	Plasma sprayed	 Air powder abrasive (test) Sterile water treated (control)
Zablotsky et al ¹⁶ (1992)	In vitro	9 titanium alloy test strips	Grit-blasted titanium alloy and hydroxylapatite- coated test strips	Grit blasted titanium alloy strips: 1. Citric acid 2. Stannous fluoride 3. Tetracycline HCl 4. Chlorhexidine gluconate 5. Hydrogen peroxide 6. Chloramine T 7. Sterile water 8. Plastic sonic scaler tip 9. Air powder abrasive unit Hydroxyapatite-coated strips: 1. Chloramine T 2. Citric acid 3. Burnished with sterile water on cotton pellets
Dennison et al ¹⁸ (1994)	In vitro	36 implants	Machined, plasma sprayed, hydroxylapatite- coated surfaces	 Cotton pellet soaked in water Citric acid solution 0.12% chlorhexidine Air powder abrasive
Augthun et al ¹⁹ (1998)	In vitro		Plasma sprayed; hydroxyapatite- coated implants; smooth titanium surface screws	 Plastic curet Metal curet Diamond polishing device Ultrasonic scaler Air-powder-water spray with sodium hydrocarbonate Chlorhexidine 0.1% solution rinse
Mouhyi et al ²¹ (1998)	In vitro	17 implants from 9 patients	Brånemark implants	 Rinsing in absolute ethanol for 10 min Cleaning in ultrasonic baths containing trichloroethylene and absolute ethanol, 10 min in each solution Abrasive cleaning for 30 s Cleaning in supersaturated citric acid for 30 s Cleaning with continuous CO2 laser in dry conditions at 5 W for 10 s Cleaning with continuous CO2 laser in wet conditions (saline) at 5 W for 10 s
Schwarz et al ²⁰ (2009)	In vitro	160 titanium disks; 48 hour biofilm	SAE surface	Air powder abrasive with amino acid glycine (three different types) or sodium bicarbonate (one type) powders; each sample received single as well as repeated treatment (20 s for both)
Persson et al ²² (2011)	Human	42 subjects		Nonsurgical treatment with: Group 1: Er:YAG laser Group 2: air abrasive subgingival polishing device

AIR = air powder abrasive; CA = citric acid solution; CHX = 0.12% chlorhexidine; SEM = scanning electron microscopy; TRI = trichloroethylene.

Although all studies evaluated surface change using SEM, there was no standard terminology or method to describe the level and character of surface change. The authors used subjective descriptions like "slight change" or "medium change;" therefore, the evaluations were not comparable. Still, the studies can be classified according to the specimen type used.

The studies on abutments reported minor surface alterations²³ or no change on the surface.²⁴ The character of the change was described as smoothing and rounding off the sharp machined grooves and obliterating the milling marks,^{25,26} obliterated metal tags, rounding of the edges,²⁷ or some surface pitting.²⁸

Other studies used implants with different surface properties as specimens. Four studies using plasma

spray-coated implants^{18,19,24,29} reported no perceptible differences or slight changes. The character of the change was reported as increased roughness of the surface³⁰ or coating removal.³¹

HA-coated implants were also tested. Coating removal on this surface as well as plasma-coated implants were reported,³¹ whereas others reported only a medium change in surface properties.¹⁹

Another type of implant used is the machined surface implant. Despite the fact that machined implants were reported to be more affected than plasma spraycoated implants, 27 studies reported no perceptible difference 29 or only the removal of the machining marks. 26 Mouhyi et al 21 reported craters of 10 μ m in diameter on machined surfaces.

Evaluation method	Results
SEM	100% removal of bacteria from the test group; 75% removal from control group
Residual lipopoly- saccharide levels were measured by liquid scintillation spectrometry	For grit blasted titanium alloy strips, air-powder abrasive was significantly superior to other treatments For hydroxyapatite-coated surfaces, citric acid was superior when compared with the controls or chloramine T
Microbiologically	Machined implants, remaining amount of endotoxin: AIR < CA with AIR = water = CHX; Plasma-sprayed implants, remaining amount of endotoxin: water = CHX = CA AIR < water = CHX = CA; Hydroxyapatite implants: AIR = CA < water < CHX; Air powder abrasive most effective. Only hydroxyapatite coated surfaces can be treated equally with air abrasive and citric acid.
SEM	Only air powder abrasive treatment yielded a clean implant without damage to the surface
SEM and x-ray induced photoelectron spectroscopy	Cleaning of used implants in citric acid followed by rinsing with deionized water for 5 min followed by cleaning in ultrasonic baths with TRI and absolute ethanol gave the best results with regard to macroscopical appearance and surface composition
Residual biofilm	100% cleaning of the biofilm areas in all groups
Microbiological assessment	Both treatments failed to reduce the bacterial counts at 6 months

Two studies used sandblasted and acid-etched (SAE) surface titanium specimens.^{20,32} Kreisler et al³² reported microscopically visible changes and smoother surface and Schwarz et al²⁰ mentioned obvious alteration of the specific SAE surface morphology. In another study,³³ bioactive glass powder was applied on machined surfaces instead of conventional grit blasting to achieve a rough surface. Bioactive glass was distributed across the titanium surface and retained within fissures and roughened surface features.

The alterations were influenced by the application time. The studies that reported no perceptible difference on implant surface had an air abrasive treatment application time of less than 30 seconds. ^{24,29,34} However, others ³⁰ reported decreased roughness after a 2-second

application, and one study²⁷ reported rounding and removal of the machining groves after a 5-second application. Chairay et al³⁴ reported that although a 5-second application did not induce deep changes, a 15-second application modified the specimen surfaces on machined and plasma spray-coated implants.

According to these studies, air powder abrasive treatment results in minor rounding of the sharp edges but does not create big surface changes. Most of these studies were done on older types of implants such as machined, plasma spray-coated, or HA-coated implants that are not commonly used today. However, implants that have been inserted can still develop peri-implantitis and, thus, may need treatment.

Study (y)	Type	Specimen type (no.)	Treatment method	
Parham et al ¹⁷ (1989)	In vitro	28 plasma-sprayed implants	Air powder abrasive Sterile water treated	
Barnes et al ²⁹ (1991)	In vitro	4 machined, 4 plasma-sprayed, 4 highly-polished implants	Air abrasive treatment (10 s)	
McCollum et al ²⁸ (1992)	In vitro	5.5 mm-abutments	 Plastic scalers Air powder abrasive system 30 seconds Rubber cup polishing with pumice 	
Koka et al ²⁶ (1992)	In vitro	Brånemark titanium implants	Prophy jet and microprophy system for 90 s	
Homiak et al ²⁵ (1992)	In vitro	5 new 10-mm titanium implant abutments	 Metal scaler Plastic scaler Rubber cup Rubber cup with tin oxide Air powder abrasive (Cavi-Jet) (5 seconds-50 seconds) 2 phases, 1st: short, 2nd: long 	
Matarasso et al ³⁰ (1996)	In vitro	50 Straumann bonefit (plasma- spray) implants	 Ultrasonic scaler Plastic tip ultrasonic scaler Stainless steel curette Titanium curette Teflon curette Air powder abrasive (max air: 5 k/cm2, max water: 2 k/cm2) 1 to 2 s Abrasive rubber cups Polishing rubber cup and brush 	
Meschenmoser et al ²³ (1996)	In vitro	5 new titanium implant abutments	 Steel curet Prototype pure titanium curet Air abrasive polishing system - 30 s Ultrasonic system 	
Chairay et al ³⁴ (1997)	In vitro	4 machined, 4 plasma-sprayed; Both neck and body surfaces of the implants were analyzed	Air abrasive 5 s and 15 s	
Brookshire et al ²⁷ (1997)	In vitro	Pure titanium and titanium alloy abutments	 Gold alloy tipped scaler High grade resin scaler Graphite reinforced scaler Air powder abrasive treatment 20 s Rubber cup with tin oxide slurry 	
Mengel et al ²⁴ (1998)	In vitro	Titanium implants and abutments; plasma-sprayed implants; stan- dard Brånemark implants	 Titanium curettes Gracey curettes Plastic curettes Plastic curettes Rubber cups with Zircate prophy paste Cavitron jet ultrasonic scaler Air polishing nozzles with Prophy Jet cleaning powder (20-s pressure: 3 bars) Dentsonic sonic scaler 	
Augthun et al ¹⁹ (1998)	In vitro	Plasma-sprayed, hydroxyapatite- coated implants; and smooth titanium surface screws	 Plastic curettes Metal curettes Diamond polishing device, Ultrasonic scaler Air-powder-water spray with sodium hydrocarbonate solution Chlorhexidine 0.1% solution rinse 	
Mouhyi et al ²¹ (1998)	In vitro	17 Brånemark implants from 9 patients	 Rinsing in absolute ethanol for 10 min Cleaning in ultrasonic baths containing trichloroethylene and absolute ethanol, 10 min in each solution Abrasive cleaning for 30 s Cleaning in supersaturated citric acid for 30 s Cleaning with continuous CO2 laser in dry conditions at 5 W for 10 s Cleaning with continuous CO2 laser in wet conditions (saline) at 5 W for 10 s 	
Kreisler et al ³² (2005)	In vitro	SAE surface titanium platelets	Er:YAG laser Air powder abrasive with sodium bicarbonate	

Evaluation r	method	Results
SEM		es in the surface topography, rounding of angles and edges of the plasma spray occasional surface pitting
SEM	No perceptib	le difference regarding surface integrity
SEM		orasive largely obliterated the marks caused by milling and surface pitting; g of the surface
SEM and EDS	Microprophy;	arks were completely removed by the Prophy Jet and partially removed by the both appeared smoother. A noncrystalline deposit was observed on the surface ent cylinder exposed to the Microprohy, which was revealed to be sodium.
SEM and optical mid		er abrasive treatment rounded many of the sharp edges; further smoothing of the machined grooves
SEM and optical mic prophylometer analy		orasive (2 s in min and max) increased the roughness
SEM and confocal la microscope	ser scanning All instrumen	ts caused surface alterations except the plastic curet
SEM	of a machine plasma-spray	brasive treatment modified the exposed surfaces. The threaded neck surface d group was least affected, whereas the body was the most altered. In the red group surface, change was little. In all specimens, 5-s exposure did not changes in the surfaces, 15-s exposure modified all the specimen surfaces.
SEM	After 20 s: th	osure: slight rounding of the previously irregular edges of the metal tags be edges became even more rounded but no significant surface alteration was the air powder abrasive system
SEM; optical laser p	rofilometry Cavitron jet a the implant s	irpolishing system left the implant surfaces unchanged; no visible change to urfaces
SEM		age: air powder abrasive, chlorhexidine, and curettage with a plastic aused little or no damage
SEM and x-ray induc tron spectroscopy		the surface topography, numerous craters (about 10 µm in diameter) were der particles were seen on the surface
SEM	Surface prop Air powder at Er:YAG laser:	prasive: microscopically visible changes, smoother surface

Table 2 Studies Evaluating the Surface Change of Titanium after Air Powder Abrasive Treatment (cont.)

Study (y)	Туре	Specimen type (no.)	Treatment method
Ramaglia et al ³¹ (2006)	In vitro	7 HA-, 7 TPS-coated implants	 Stainless steel curette Plastic curette Ultrasonic scaler tip Air powder abrasive
Koller et al ³³ (2007)	In vitro	30 machined titanium disks	Grit blasting with bioactive glass
Schwarz et al ²⁰ (2009)	in vitro	160 SAE surface titanium disks; 48-hour biofilm	Air powder abrasive with amino acid glycine (three different types) or sodium bicarbonate (one type) powder; each sample received single as well as repeated treatment (20 s for both)

SEM = scanning electron microscopy; EDS = energy-dispersive x-ray spectroscopy; SAE = sandblasted acid-etched; HA = hydroxyapatite; TPS = titanium plasma spray.

Table 3 Studies Evaluating the Cell Response Toward the Air Powder Abrasive Treated Titanium Disks				
Study (y)	Туре	Specimen type (no.)	Treatment method	
Parham et al ¹⁷ (1989)	In vitro	28 plasma-sprayed implants	 Air powder abrasive with sodium bicarbonate Sterile water treated 	
Augthun et al ¹⁹ (1998)	In vitro	6 plasma-sprayed; 6 hydroxyapatite-coated implants; 6 smooth titanium surface screws	 Plastic curette Metal curette Diamond polishing device Ultrasonic scaler Air-powder-water spray with sodium hydrocarbonate solution Chlorhexidine 0.1% solution rinse 	
Shibli et al ³⁵ (2003)	In vitro	26 sterile abutments	1. Prophy Jet with sodium bicarbonate for 30 s	
Kreisler et al ³² (2005)	In vitro	SAE surface titanium platelets	Er:YAG laser Air powder abrasive with sodium bicarbonate	
Schwarz et al ²⁰ (2009)	In vitro	SAE surface titanium discs	 Air powder abrasive with sodium bicarbonate Air powder abrasive with amino acid glycine (distance: 1 mm to 2 mm; angle: 30 to 90 degrees) Control: noncontaminated, nontreated 	

SAE = sandblasted acid-etched.

Cell Response

Five in vitro studies evaluated the cell response toward air powder-treated titanium by cell attachment and viability tests^{17,19,20,32,35} (Table 3). Four studies applied air powder-abrasive treatment on contaminated specimens and one study applied air powder-abrasive treatment directly on sterile titanium abutments.

Cell attachment tests showed that the number of attached cells on the air powder abrasive-treated specimens is slightly lower but not significantly different than sterile, untreated control specimens or water treated controls. However, others 20,35 reported a significant decrease in the number of cells attached and lower mitochondrial activity.

The cell morphology was reported to be unaffected³⁵ and uniform attachment was observed on the disks.^{18,19}

Another parameter evaluated was cell proliferation and it was reported to be higher in the air powder abrasive-treated group compared with the laser-treated group.³²

Cell activity was compared between disks that were treated by air powder abrasive treatment with sodium bicarbonate and amino acid glycine powder.²⁰ Both groups showed significantly lower activity than sterile discs. However, sodium carbonate resulted in significantly higher values than amino acid glycine.

According to these results, cell response to air powder abrasive-treated disks decreased compared with sterile non-treated disks and was influenced by the type of powder used. However, the results did demonstrate sufficient levels of cell attachment and cell viability.

Reosseointegration

Two animal studies reported reosseointegration amounts following peri-implantitis therapy with air powder abrasive treatment^{36,37} (Table 4). In one study, 64 implants were placed in eight monkeys and ligature induced peri-implantitis was created.³⁶ Afterwards, implants were treated with different decontamination

Evaluation method	Results
SEM and profilometry	All methods showed changes related to the implant coating material; coating removal and decreasing of surface roughness; air powder abrasive and plastic curette induce less implant surface alterations
SEM residual abrasive	The roughness attained compares favorably with currently used implant designs Bioactive glass was distributed across the titanium surface and retained within fissures and roughened surface features
SEM	Surface morphology. Sodium bicarbonate powder: obvious alteration of the specific surface morphology, irregular grooves, and pits appeared to be unchanged, the sharp-edged elevations were markedly flattened Aminoacidglycine: did not result in specific surface alterations

Results

The mean numbers of attached fibroblasts was not statistically significant between test and control groups; uniform attachment over the entire implant surface

Percentage of vital cells was nearly same as control; good cell spreading was observed; mostly vital cells were found on implants sprayed with the air powder abrasive

Cell morphology was not affected by air powder abrasive treatment (no significant difference); number of cells was significantly higher in control group than test group

Cell growth was not significantly different than sterile specimens for both laser- and air powder abrasive-treated specimens; cell proliferation on air powder abrasive group was the highest

Mitochondrial activity is significantly higher in control group followed by sodium bicarbonate, which is significantly higher than amino acid glycine

methods with open surgical debridement. Among four different treatments, one group was treated with air powder abrasive and another with air powder abrasive plus citric acid. All groups showed almost complete bone fill, whereas the reosseointegration (proportion of the implant "surface" within defect covered by regenerated bone) was on average 39% to 46% for all groups. Reosseointegration was not dependent upon surface treatment.

A similar study was done with six dogs and 60 implants.³⁷ One group was treated with air powder abrasive, a second with carbon dioxide laser, and a third group with a combination of these two treatments. During surgery, one fourth of the implants received membranes. The results were evaluated with radiographs and histologic sections. The mean depth of the defects was 1.70 mm. According to radiologic results, bone fill was smallest in the air powder abrasive therapy group and larger in the laser and laser plus air powder abrasive groups. The mean bone gain on

radiographs was 0.48 mm for air abrasive treatment, 1.20 mm for laser treatment, and 0.70 mm for combination treatment. However, the histometric analyses of the histologic sections of the same samples showed no statistical difference between groups. The histometry mean bone gain in the air powder abrasive treatment group was 0.64 mm; in the laser group, 0.62mm; and in the combination treatment group, 0.75 mm. More preferable results occurred with membrane-treated implants and some reosseointegration was observed in all groups.

According to these two studies, air powder abrasive treatment does not produce any additional beneficial or detrimental effects on reosseointegration. However, not enough studies exist to make a definitive conclusion on this subject.

Clinical Outcome

Air powder abrasive treatment can be employed in peri-implantitis therapy either with open surgical

The International Journal of Oral & Maxillofacial Implants 1469

Table 4 Studies Evaluating Reosseointegration Following Air Powder Abrasive Treatment Implant no. Study (y) and type **Test groups** Deppe et al³⁷ (2001) 6 dogs; 60 TPS implants Group 1: air powder abrasive Group 2: CO2 laser Group 3: Prophy Jet and CO2 laser; each group consisted of four hemimandibles, three received one nonresorbable membrane, whereas the fourth did not Schou et al³⁶ (2003) 8 monkeys; 64 TPS implants Group 1: air powder abrasive unit plus citric acid Group 2: air powder abrasive unit Group 3: gauze soaked in saline plus citric acid Group 4: gauze soaked alternately in chlorhexidine and saline All groups: autogenous bone and ePTFE membrane Antibiotic: systemic metronidazole, systemic ampiciline

Table 5 Studies Evaluating the Clinical Response Following the Air Powder Abrasive Treatment				
Study (y)	No. of implants	Decontamination method		
Duarte et al ³⁹ (2009)	10 healthy control; 10 mucositis; 20 peri-implantitis	Mucositis group: mechanical debridement with air powder abrasive and resin curettes Peri-implantitis group: open surgical debridement using air powder abrasive and resin curettes		
de Mendonca et al ⁴⁰ (2009)	10 patients; 10 implants	Flap elevation plus resin curettes plus air powder abrasive with sodium bicarbonate		
Maximo et al ⁴¹ (2009)	35 subjects: 10 healthy; 12 mucositis; 13 peri-implantitis Implant type: Brånemark system	Peri-implantitis treatment: flap elevation plus Teflon curettes plus air abrasive sodium carbonate air powder		
Renvert et al ³⁸ (2011)	42 subjects; 100 implants (70 machined; 30 medium rough)	No surgical operation: Group 1: air powder abrasive device nozzle was placed in the pocket, used for approximately 15 s Group 2: Er:YAG laser at an energy level of 100 mJ/pulse and 10 Hz (12.7 J/cm²)		

debridement or subgingivally without raising the flap. Four studies on air powder abrasive treatment with surgery were found in the literature^{38–41} (Table 5). One randomized clinical trial compared Er:YAG laser and air powder abrasive in noninvasive peri-implantitis treatment.³⁸ Microbiological results⁴¹ and clinical outcome³⁹ were reported in two articles. Three case series^{39–41} reported the outcome of open surgical treatment with air

powder abrasive treatment. All case series reported significant improvement in all clinical parameters such as marginal bleeding, bleeding on probing, suppuration, and probing depth after both 3 and 12 months.^{39–41} The studies that used air powder abrasive treatment nonsurgically, without raising the flap, reported limited improvement. One study³⁸ reported a slight reduction in probing pocket depth, frequency of suppuration, and

TPS = titanium plasma spray.

Observa period		method	Results
4 mo	Histologic	implant a laser cor All meas Histology minimal amounts reosseoi groups.	urements considered entire defects. y: without membranes; group 1 demonstrated new bone regeneration; groups 2 and 3 showed large of rapidly formed bone; all groups showed some integration. With membranes: better results in all tric evaluation: no statistical difference between groups
6 mo	Histologic and radiograph	reosseoi applied;	complete bone regeneration and considerable integration were obtained irrespective of the method a mean bone-to-implant contact of 39% to 46% was d within the defects

Observation period	Evaluation method	Results
3 mo	Clinical observation: interleukin (IL)-4, -10, -12 TNF- α osteoprotegerin and peri-implant crevicular fluid were measured by enzyme-linked immunosorbent assay	Significant improvement in all clinical parameters for mucositis and peri-implantitis. TNF- α levels were significantly reduced achieving the same level as the healthy group at 3 mo.
3 and 12 mo	Clinical parameters and TNF- $\!\alpha$ levels	Clinical parameters were significantly improved at 3 and 12 months. TNF- α levels decreased from 3 to 12 mo after therapy. Significantly positive correlations were found between TNF- α and bleeding on probing and probing depth.
3 mo	Clinical parameters and microbiologic counts	Clinical parameters were reduced significantly; microbiological counts also decreased significantly after treatment
6 mo	Clinical and radiographic assessment	Both methods resulted in a reduction of probing pocket depth, the frequency of suppuration, and bleeding at implants but there was no significant difference between the groups; overall clinical improvement was limited. Alveolar bone change failed to demonstrate differences between baseline and 6 mo.

bleeding but did not reach the healthy level and another²² reported that clinical improvements were limited.

It can be concluded that air powder abrasive cleaning as an implant surface cleaning method may result in improved clinical parameters as long as it is used in combination with surgical treatment. However, noninvasive use of air powder abrasive treatment does not show significant improvement.

DISCUSSION

Considering air powder abrasive treatment as an implant surface treatment method, there are several aspects to be evaluated. Safety is as important as efficiency since the method will be used subgingivally and on the specific surface of a titanium implant. Because of this fact, several in vitro studies were performed

The International Journal of Oral & Maxillofacial Implants 1471

before the method was clinically applied. Although these in vitro studies provide a general idea on the method, they should be supported by future in vivo studies.

All in vitro studies on the cleaning efficiency of air powder abrasive treatment reported consistent results. Although the studies varied in design (different implant types, endotoxin contamination or intraoral keeping, SEM observation or light microscope, staining or no staining), the cleaning efficiency of the method always resulted in high values ranging between 85% and 100%. 16-20 However, the only clinical study on this subject reports low bacterial reduction at 2 months and no reduction at 6 months.²² The reason that the in vivo result is not in agreement with in vitro studies could be due to the different application methods. In this randomized clinical trial, air powder abrasive was applied without raising the flap. This makes it difficult or perhaps impossible for the powder to reach the implant surface. Additionally, nonsurgical therapy on peri-implantitis lesions was already concluded to be ineffective.1 Therefore, this study may not be enough to draw conclusions on the efficiency of air powder abrasive therapy since the unsuccessful reduction of bacterial counts could be due to nonsurgical therapy.

Another concern about air powder abrasive treatment is the possible damage that it may cause on the implant surface. According to the in vitro studies, slight to medium change is observed on the treated surfaces. 19,20,25,28,29,31,32,34 However, there is no standard evaluation method to report the level of damage. The results have to be reported in a subjective way. This makes it difficult to compare studies and draw conclusions. However, descriptions of the damage are similar in all studies reporting small craters, rounding, or the removal of sharp edges. Since no dramatically big changes were reported, the method could be considered safe in this respect.

The effect of the treated surface on reosseointegration is evaluated by cell response in a number of studies. ^{18–20,32,35} The results show that cell response changes depending on application time and powder type. ²⁰ It can be concluded that the residual powder particles on the titanium surface may influence the cell response. Thus, the cell response may be improved by using biocompatible powders.

Reosseointegration following air powder abrasive treatment was tested in animal studies. The amount of reosseointegration observed was not significantly different than other cleaning methods.^{22,37} However, clinicians need to keep in mind that reosseointegration is very difficult to achieve. In order to have a good level of reosseointegration, the original peri-implant condition should be restored.⁴² Because contamination of the implant surface results in a lowering of the surface

free energy,⁴³ the chance of bone growing into contact with the titanium surface is low.⁴⁴ No treatment method has been described in the literature to be predictable in achieving sufficient reosseointegration.

Although there are hardly any studies reporting on the clinical outcome of air powder abrasive treatment, available studies report improved clinical parameters following the treatment.^{39–41} However, the method should be applied directly on the implant surface after raising the flap. Nonsurgical treatment does not result in significant improvements.³⁸ At this point, the complications that can be caused by this method need to be considered. Abrasion in the soft tissue and air emphysema may be seen following application. Air emphysema is reported following tooth cleaning or implant maintenance with air powder abrasive treatment with sodium bicarbonate. 45-48 However, in other studies, 14,15 amino acid glycine, a softer powder specially developed for subgingival applications, was used on 74 patients subgingivally with a lower air pressure. No case of air emphysema was seen in these studies.

CONCLUSION

Air powder abrasive treatment gives promising results. The method should be improved for it to be used safely on implant surfaces. If the modified air powder abrasive treatment is gentle enough not to harm the bone and soft tissue, as well as efficient enough to remove all deposits, the amount of reosseointegration following treatment could be increased.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

REFERENCES

- Lindhe J, Meyle J, Group D of European Workshop on Periodontology. Peri-implant diseases. Consensus Report of the Sixth European Workshop on Periodontology. J Clin Periodontol 2008;35(suppl):282–285.
- Mombelli A, Lang NP. The diagnosis and treatment of periimplantitis. Periodontol 2000 1998;17:63–76.
- Quirynen M, Vogels R, Peeters W, van Steenberghe D, Naert I, Haffajee A. Dynamics of initial subgingival colonization of "pristine" peri-implant pockets. Clin Oral Implants Res 2006;17:25–37.
- van Winkelhoff AJ, Goené RJ, Benschop C, Folmer T. Early colonization of dental implants by putative periodontal pathogens in partially edentulous patients. Clin Oral Implants Res 2000;11:511–520.
- Salinas T, Eckert S. Implant-supported single crowns predictably survive to five years with limited complications. J Evid Based Dent Pract 2010;10:56–57.
- Aglietta M, Siciliano VI, Zwahlen M, et al. A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clin Oral Implants Res 2009;20:441–451.

- Triplett RG, Andrews JA, Hallmon WW. Management of peri-implantitis. Oral Maxillofac Surg Clin North Am 2003;15:129–138.
- Renvert S, Polyzois I, Maguire R. Re-osseointegration on previously contaminated surfaces: A systematic review. Clin Oral Implants Res 2009:20:216–227.
- Wetzel AC, Vlassis J, Caffesse RG, Hämmerle CH, Lang NP. Attempts to obtain re-osseointegration following experimental peri-implantitis in dogs. Clin Oral Implants Res. 1999;10:111–119.
- Romanos G, Ko HH, Froum S, Tarnow D. The use of CO(2) laser in the treatment of peri-implantitis. Photomed Laser Surg 2009;27:381–386.
- Sawase T, Jimbo R, Wennerberg A, Suketa N, Tanaka Y, Atsuta M. A novel characteristic of porous titanium oxide implants. Clin Oral Implants Res 2007;18:680–685.
- Suzuki T, Hori N, Att W, et al. Ultraviolet treatment overcomes timerelated degrading bioactivity of titanium. Tissue Eng Part A 2009;15: 3679–3688.
- Aita H, Att W, Ueno T, et al. Ultraviolet light-mediated photofunctionalization of titanium to promote human mesenchymal stem cell migration, attachment, proliferation and differentiation. Acta Biomater 2009;5:3247–3257.
- Moëne R, Décaillet F, Andersen E, Mombelli A. Subgingival plaque removal using a new air-polishing device. J Periodontol 2010;81:79–88.
- Petersilka GJ, Tunkel J, Barakos K, Heinecke A, Häberlein I, Flemmig TF. (2003) Subgingival plaque removal at interdental sites using a low-abrasive air polishing powder. J Periodontol 2003;74:307–311.
- Zablotsky MH, Diedrich DL, Meffert RM. Detoxification of endotoxin-contaminated titanium and hydroxyapatite-coated surfaces utilizing various chemotherapeutic and mechanical modalities. Implant Dent 1992;1:154–158.
- Parham PL Jr, Cobb CM, French AA, Love JW, Drisko CL, Killoy WJ. Effects of an air-powder abrasive system on plasma-sprayed titanium implant surfaces: An in vitro evaluation. J Oral Implantol 1989;15:78–86.
- Dennison DK, Huerzeler MB, Quinones C, Caffesse RG. Contaminated implant surfaces: An in vitro comparison of implant surface coating and treatment modalities for decontamination. J Periodontol 1994:65:942–948.
- Augthun M, Tinschert J, Huber A. In vitro studies on the effect of cleaning methods on different implant surfaces. J Periodontol 1998; 69:857–864.
- Schwarz F, Ferrari D, Popovski K, Hartig B, Becker J. Influence of different air-abrasive powders on cell viability at biologically contaminated titanium dental implants surfaces. J Biomed Mater Res B Appl Biomater 2009;88:83–91.
- Mouhyi J, Sennerby L, Pireaux JJ, Dourov N, Nammour S, Van Reck J. An XPS and SEM evaluation of six chemical and physical techniques for cleaning of contaminated titanium implants. Clin Oral Implants Res 1998;9:185–194.
- Persson GR, Roos Jansåker AM, Lindahl C, Renvert S. Microbiologic results after non surgical erbium-doped:yttrium, aluminum, and garnet laser or air-abrasive treatment of peri-implantitis: A randomized clinical trial. J Periodontol 2011;82:1267–1278.
- Meschenmoser A, d'Hoedt B, Meyle J, et al. Effects of various hygiene procedures on the surface characteristics of titanium abutments. J Periodontol 1996;67:229–235.
- 24. Mengel R, Buns CE, Mengel C, Flores-de-Jacoby L. An in vitro study of the treatment of implant surfaces with different instruments. Int J Oral Maxillofac Implants 1998;13:91–96.
- Homiak AW, Cook PA, DeBoer J. Effect of hygiene instrumentation on titanium abutments: A scanning electron microscopy study. J Prosthet Dent 1992;67:364–369.
- Koka S, Han J, Razzoog ME, Bloem TJ. The effects of two air-powder abrasive prophylaxis systems on the surface of machined titanium: A pilot study. Implant Dent 1992;1:259–265.
- Brookshire FV, Nagy WW, Dhuru VB, Ziebert GJ, Chada S. The qualitative
 effects of various types of hygiene instrumentation on commercially
 pure titanium and titanium alloy implant abutments: An in vitro and
 scanning electron microscope study. J Prosthet Dent 1997;78:286–294.
- McCollum J, O'Neal RB, Brennan WA, Van Dyke TE, Horner JA.
 The effect of titanium implant abutment surface irregularities on plaque accumulation in vivo. J Periodontol 1992;63:802–805.

- 29. Barnes CM, Fleming LS, Mueninghoff LA. SEM evaluation of the invitro effects of an air-abrasive system on various implant surfaces. Int J Oral Maxillofac Implants 1991;6:463–469.
- Matarasso S, Quaremba G, Coraggio F, Vaia E, Cafiero C, Lang NP. Maintenance of implants: An in vitro study of titanium implant surface modifications subsequent to the application of different prophylaxis procedures. Clin Oral Implants Res 1996;7:64–72.
- 31. Ramaglia L, di Lauro AE, Morgese F, Squillace A. Profilometric and standard error of the mean analysis of rough implant surfaces treated with different instrumentations. Implant Dent 2006;15:77–82.
- Kreisler M, Kohnen W, Christoffers AB, et al. In vitro evaluation of the biocompatibility of contaminated implant surfaces treated with an Er:YAG laser and an air powder system. Clin Oral Implants Res 2005;16:36–43.
- Koller G, Cook RJ, Thompson ID, Watson TF, Di Silvio L. Surface modification of titanium implants using bioactive glasses with air abrasion technologies. J Mater Sci Mater Med 2007;18:2291–2296.
- 34. Chairay JP, Boulekbache H, Jean A, Soyer A, Bouchard P. Scanning electron microscopic evaluation of the effects of an air-abrasive system on dental implants: A comparative in vitro study between machined and plasma-sprayed titanium surfaces. J Periodontol 1997;68:1215–1222.
- Shibli JA, Silverio KG, Martins MC, Marcantonio júnior E, Rossa júnior C. Effect of air-powder system on titanium surface on fibroblast adhesion and morphology. Implant Dent 2003;12:81–86.
- Schou S, Holmstrup P, Jørgensen T, et al. Implant surface preparation in the surgical treatment of experimental peri-implantitis
 with autogenous bone graft and ePTFE membrane in cynomolgus
 monkeys. Clin Oral Implants Res 2003;14:412–422.
- Deppe H, Horch HH, Henke J, Donath K. Per-implant care of ailing implants with the carbon dioxide laser. Int J Oral Maxillofac Implants 2001:16:659–667.
- Renvert S, Lindahl C, Roos Jansåker AM, Persson GR. Treatment of peri-implantitis using an Er:YAG laser or an air-abrasive device: A randomized clinical trial. J Clin Periodontol 2011;38:65–73.
- Duarte PM, de Mendonça AC, Máximo MB, Santos VR, Bastos MF, Nociti FH. Effect of anti-infective mechanical therapy on clinical parameters and cytokine levels in human peri-implant diseases. J Periodontol 2009;80:234–243.
- de Mendonça AC, Santos VR, César-Neto JB, Duarte PM. Tumor necrosis factor-alpha levels after surgical anti-infective mechanical therapy for peri-implantitis: A 12-month follow-up. J Periodontol 2009;80:693–699.
- Máximo MB, de Mendonça AC, Renata Santos V, Figueiredo LC, Feres M, Duarte PM. Short-term clinical and microbiological evaluations of peri-implant diseases before and after mechanical antiinfective therapies. Clin Oral Implants Res 2009;20:99–108.
- Baron M, Haas R, Dörtbudak O, Watzek G. Experimentally induced peri-implantitis: A review of different treatment methods described in the literature. Int J Oral Maxillofac Implants 2000;15:533–544.
- 43. Bair RE, Meyer AE. Implant surface preparation. Int J Oral Maxillofacial Implants 1988;3:9–20.
- 44. Kubies D, Himmlová L, Riedel T, et al. The interaction of osteoblasts with bone-implant materials: 1. The effect of physicochemical surface properties of implant materials. Physiol Res 2011;60:95–111.
- Van de Velde E, Thielens P, Schautteet H, Vanclooster R. Subcutaneous emphysema of the oral floor during cleaning of a bridge fixed on an IMZ implant. Case report [in French]. Rev Belge Med Dent (1984) 1991;46:64–71.
- Bergendal T, Forsgren L, Kvint S, Löwstedt E. The effect of an airbrasive instrument on soft and hard tissues around osseointegrated implants. A case report. Swed Dent J 1990;14:219–223.
- 47. Finlayson RS, Stevens FD. Subcutaneous facial emphysema secondary to use of the Cavi-Jet. J Periodontol 1988;59:315–317
- Liebenberg WH, Crawford BJ. Subcutaneous, orbital, and mediastinal emphysema secondary to the use of an air-abrasive device. Quintessence Int 1997;28:31–38.