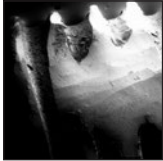




Decontamination of the Infected Implant Surface: A Scanning Electron Microscope Study



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A number of treatment options have been explored for peri-implantitis. Seven rough-surfaced implants that failed from peri-implantitis were retrieved. Surfaces were treated by different methods: saline, chlorhexidine, citric acid, 35% phosphoric acid etch gel, hydrogen peroxide, implantoplasty, airborne-particle abrasion, laser, and titanium brush. Implants were observed under scanning electron microscopy. Chemical agents failed to remove any biologic debris. Airborne-particle abrasion, laser, and titanium brush removed part of the biologic debris, and implantoplasty showed complete biologic debris removal. In ex vivo failed implants, implantoplasty showed complete disturbance and removal of bacterial biofilm.
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Peri-implantitis is a pathologic condition occurring in the tissues around dental implants, characterized by inflammation in the peri-implant connective tissue and progressive loss of supporting bone.¹ If left untreated, this inflammation can lead to complete implant failure and loss. The treatment goal with peri-implantitis is elimination of bacterial colonization, implant preservation, improved esthetics, reductions in bony defects, and regeneration of lost bone structure.

Many studies have reported and presented treatment options for peri-implantitis, though these are often based on clinical case reports. Additionally, prior studies have described different methods of treatment for peri-implantitis; these methods can be divided into two main types: chemical and physical. Chemical agents, such as citric acid, saline, hydrogen peroxide, chlorhexidine and 35% phosphoric acid gel, have been reported as treatment options,^{2–4} with nonconclusive evidence in their efficacy.^{5–7}

Physical agents can be subdivided into mechanical and laser decontamination techniques.⁸ Mechanical agents include airborne-particle abrasion,⁹ though conflicting reports have shown treatment failures or yielded insufficient data to make any conclusion of its benefit.^{10,11} Additionally, there is a high risk of air

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embolism when this method is used surgically,^{12,13} as well as high risk of contamination with the bicarbonate powder.¹⁴ Titanium brush has also been proposed as a surgical treatment,^{2,15,16} though more studies are needed to prove its efficacy.

Implantoplasty, a procedure that is done to smooth contaminated implant surfaces, is another model of surgical treatment that has also been described at length in the literature.¹⁷ Though implantoplasty has been shown to be effective for the treatment of peri-implant infections and inhibiting peri-implantitis progression,¹⁸ the procedure has also been shown to weaken narrower implants and impact mechanical strength.¹⁹

The Er:YAG laser has also been widely proposed as an effective method of treatment due to its bactericidal effect and can be used as a nonsurgical approach,^{20,21} but recent studies have shown ineffectiveness of its application.^{6,22}

Due to the numerous treatment options available, clinicians face a challenge when considering which treatment is most appropriate for providing decontamination, as there is no consensus in the literature about validated and efficacious treatment of peri-implantitis. In order to choose the appropriate treatment, a clinician should first understand the goals of the decontamination therapy, which are:

- Inflammation control
- Complete removal of the bacterial biofilm and detoxification of the implant surface to prevent recurrence

- Creation of a healthy environment for regeneration
- Provision of a safe treatment with no or minimal side effects

The purpose of this pilot study of ex vivo implants is to test the efficacy of different treatment modalities in the removal of the biologic debris (which can be a biofilm, calculus, necrotic bone residue, or a combination) from infected implant surfaces, using a scanning electron microscope (SEM) for measuring the outcome of interest.

Materials and Methods

Seven retrieved implants—with surfaces including: SLA, Straumann; TiUnite, Nobel Biocare; and MTX, Zimmer Biomet—that had failed due to peri-implantitis were collected from seven different patients in the postgraduate clinic of Periodontology and Implant Dentistry at New York University College of Dentistry. These implants were diagnosed as hopeless by the supervising faculty, using an internal criteria whereby any implant that has > 50% bone loss and is unable to be grafted will be removed using a standardized internal protocol. Therefore, these implants were considered biologic samples (medical waste) due to the surface contamination. There was no identifiable patient information, and a review from an internal review board was not needed. The principal investigator completed a self-certification form for the study, as the activities did not involve human subjects.

After retrieval, any visible calculus or debris was removed using a scaler, per standard of care. The specimens were then immediately placed in buffer formaldehyde solution fixer and stored. After 24 hours, the specimens were removed from the fixer solution and left in a disposable plastic dish and rinsed thoroughly for 1 hour. The specimens were then air-dried for 15 minutes and mounted in a glass slab using epoxy glue until set. The specimens were then placed in the environmental SEM (EVO 50, Zeiss; or S-3500N, Hitachi). The specimens did not require any kind of coating due to the fact that both SEMs used can image specimens under low vacuum (environmental SEM). The vacuum used was 100 Pa and the voltage was 15.00 kV. The images were taken in different magnifications and working distance length.

Images were taken at different power levels for all the specimens before any surface decontamination efforts were implemented. After completing the images, the specimens were removed from the SEM chamber.

The testing treatments were conducted by one examiner (J.R.) and the SEM images were conducted by three separate, calibrated examiners (M.A., K.A., and A.A.). The treated implants were grouped as follows: Group A used chemical debridement via the individual agents of hydrogen peroxide 3%, saline, phosphoric acid gel 35% (Dentsply Sirona), chlorhexidine gluconate 0.12% (Peridex, 3M ESPE), and 40% citric acid (pH = 1). Group B used

mechanical debridement using (individually) implantoplasty, titanium brush (TiBrush, Straumann), and airborne-particle abrasion with sodium bicarbonate (Cavitron Prophy Jet, Dentsply Sirona). Group C used laser debridement using an Er:YAG laser (Waterlase, Biolase) (Table 1).

For Group A, three implants (SLA and TiUnite surfaces) were randomly assigned and labeled with numbers from one to three. The treatment sequence was as follows: all three implants were treated by hand scrubbing with one of the chemical agents soaked on a cotton pellet for 60 seconds, and then placed in the SEM chamber of Zeiss EVO 50 separately. The surfaces were analyzed, and images were taken. The specimens were removed from the SEM chamber and washed with running tap water for 1 hour before the next chemical agent was applied. The addition of chemicals on the same specimen had no carry-over effect from prior tested treatments.²³ All three implants had the following sequence of treatment: saline, hydrogen peroxide 3%, phosphoric acid gel 35%, chlorhexidine gluconate 0.12%, and 40% citric acid.

The remaining specimens were randomly assigned for Groups B and C. The specimen assigned for Group B—implantoplasty (SLA surface) was labeled number four and treated by resecting the rough implant surface by using a rotary instrument with first a fine diamond bur, followed by a fine carbide bur (Diamond: 39011-052, 859EF, EF.31.010, 390UF.31.016; carbide: H48LUF.31.012, H246LU.31.012; Brasseler). The goal was to remove

Table 1 Tested Treatment Methods for Debridement on Retrieved Implants That Failed Due to Peri-implantitis

Group A: chemical debridement	Group B: mechanical debridement	Group C: laser debridement
Saline	Airborne-particle abrasion	Er:YAG laser
Hydrogen peroxide 3%	Titanium brush	
Phosphoric acid gel 35%	Implantoplasty	
Chlorhexidine gluconate 0.12%		
Citric acid 40%		

the rough surface until reaching pure titanium. The instrumentation ceased when a polished titanium surface was achieved up to the threads of the implant.

The specimen assigned to Group B—airborne-particle abrasion (MTX surface) was labeled number five and treated by applying the airborne particles on the infected implant surface by moving the hand piece from top to bottom of the implant until complete removal of surface contamination was visualized by the operator with the aid of surgical loupe at $\times 2.5$ (allowing for a greater field of view). The specimen assigned to Group B—titanium brush (SLA surface) was labeled number six and treated according to the manufacturer's instructions.

The specimen that was assigned to Group C—laser (MTX surface) was labeled number seven. The machine was set to the predetermined manufacturer setting using the closed approach with the insert RFPT5 Biolase from Waterlase, preset to the following: Power: 1.5 W; frequency: 30 Hz; Air: 40; Water: 50. The beam was passed along the outer area and inner side of the thread, as well as the surface in between. The implant was examined

for the removal of biologic debris after each passage, not for the removal of the surface texture as with the other mechanical debridement. The same imaging procedure after each treatment model in all groups was applied to every specimen.

To evaluate the specimens, SEM was used to scan the entirety of the implant. The SEM is a nondestructive testing device that can be used to examine surface topography and chemical composition and display clear images about the tested specimens. In evaluating the amount of biofilm removal, the specimens were scored from 0 to 2 by a single examiner (E.E.C.). The following criteria were used to determine the score: 0 = displayed no removal of biofilm; 1 = some removal of biofilm; 2 = complete removal of biofilm.

Results

A mass of organic film was found occupying the surface of all the retrieved implants; this was evident in the SEM images taken before the treatment initiation. This biologic debris varied in the degree of darkness and was easily differentiated from the implant surface



Fig 1 SEM image taken before treatment.

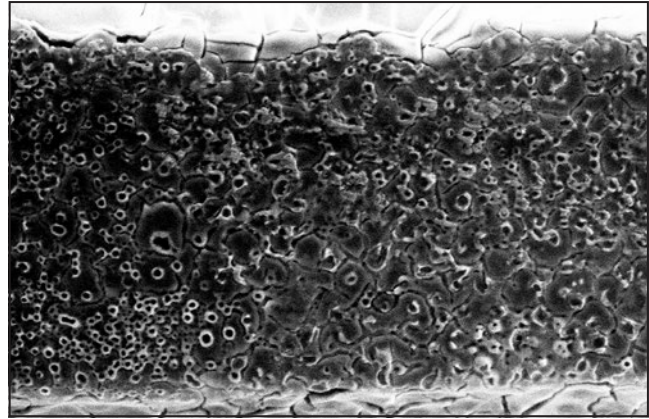


Fig 2 SEM image taken after the treatment with citric acid, showing the resulting fissures on the implant surface.

Table 2 Treatment Scores by Tested Agent

Group A: chemical debridement		Group B: mechanical debridement		Group C: laser debridement	
Agent	Score	Tool	Score	Tool	Score
Saline	0	Airborne-particle abrasion	1	Er: YAG laser	1
Hydrogen peroxide 3%	0	Titanium brush	1		
Phosphoric acid gel 35%	0	Implantoplasty	2		
Chlorhexidine gluconate 0.12%	0				
Citric acid 40%	0				

Scores: 0 = no removal of biofilm; 1 = some removal of biofilm; 2 = complete removal of biofilm.

(Fig 1). The level of implant surface roughness varied from one implant to another. Small pores, sized 0.5 to 5.0 μm , were observed in some of the implants. No mechanical damage was evident in any of the implant specimens before the treatment was observed. Some fissures were observed on some of the implant surfaces after completion of citric acid treatment (Fig 2).

For the samples treated by chemical agents in Group A, the biologic debris was still evident in the SEM images and these agents were given a score of 0 (Fig 3). Treatment in Group B with airborne-particle abrasion or titanium brush resulted in some removal of the biologic debris and was given a score of 1 (Figs

4a to 4c). Treatment with implantoplasty resulted in removal and disruption of the biologic debris that was occupying the implant surface, and this treatment was given a score of 2 (Fig 4d). Laser treatment in Group C resulted in some removal of the biologic debris; since residual biologic debris was evident, this treatment was given a score of 1 (Fig 5). A summary of the scores by treatment is displayed in Table 2.

Discussion

Existing published literature on peri-implantitis treatment is in agreement regarding the necessity of removing debris from the surface

of diseased implants. This debris can be biofilm alone, calculus, necrotic bone, or a combination of all of these elements. This pilot study showed great discrepancy between the chemical and mechanical treatments. Even within the mechanical group, differences were noted. Prior clinical studies and reports have shown that an efficacious response to peri-implantitis treatment is one that combines chemical and mechanical therapies with or without photodynamic therapy (laser) or photodynamic therapy alone.^{10,20,24}

The question that still remains is whether complete removal of debris is essential to allow for bone regeneration and successful reosseointegration. Is it possible that

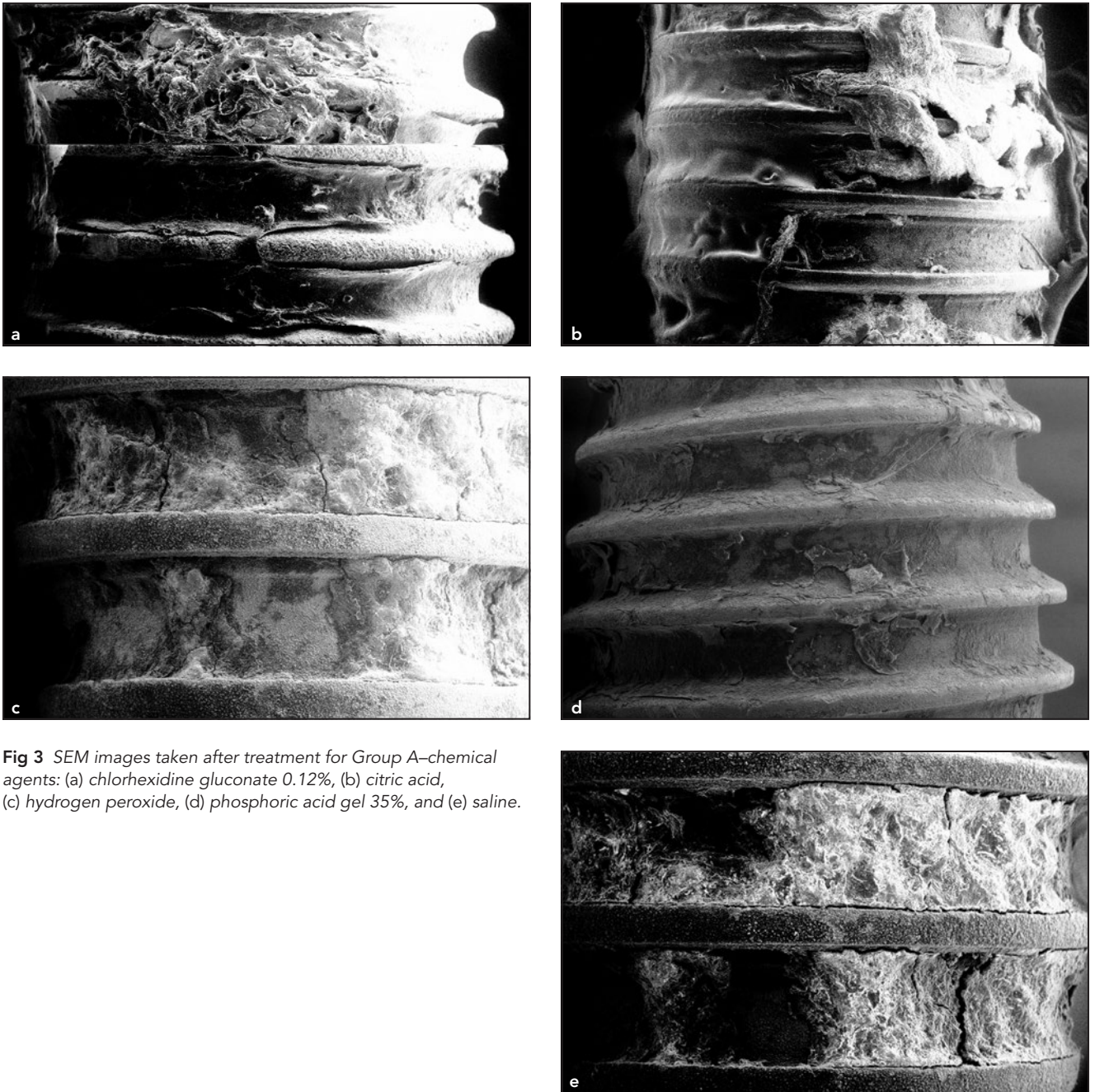


Fig 3 SEM images taken after treatment for Group A—chemical agents: (a) chlorhexidine gluconate 0.12%, (b) citric acid, (c) hydrogen peroxide, (d) phosphoric acid gel 35%, and (e) saline.

disturbance by partial removal and sterilization with chemical or photodynamic therapy is enough to allow a resolution and bone regeneration with reosseointegration? If complete removal of biologic debris alone allows for bone regeneration, then

implantoplasty (as demonstrated in this pilot study) may be capable of achieving that goal. While implantoplasty is superior in biofilm removal, there is no data available from this study to affirm that implantoplasty is a superior method of treatment

for peri-implantitis, since the treatment of peri-implantitis was not an objective of the study. The only way to validate this finding would be to conduct an animal study that induces peri-implantitis, explant, treat with the different above stated

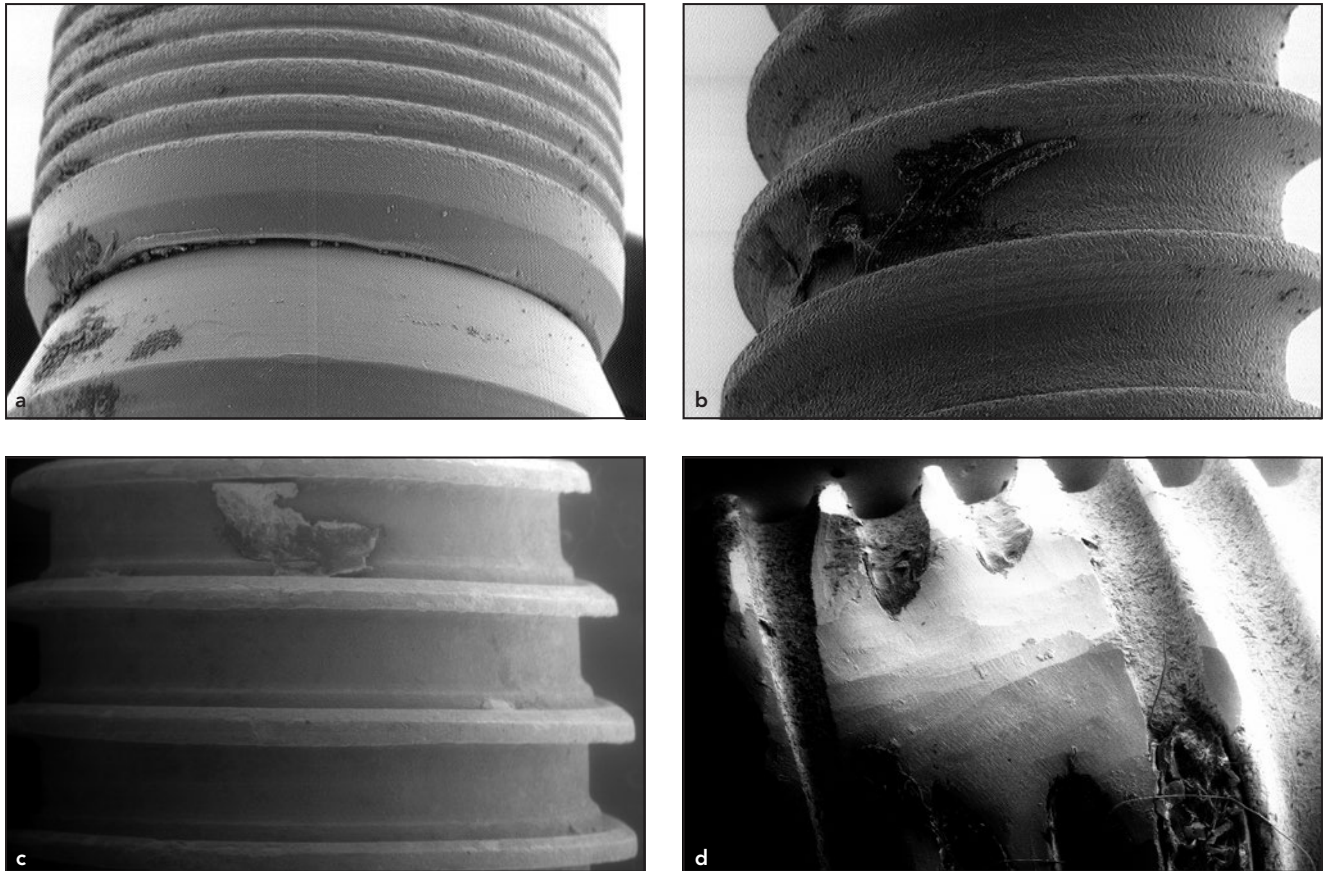


Fig 4 SEM images taken at different magnifications following treatment for (a and b) Group B–airborne-particle abrasion and (c) Group B–titanium brush. Results show some removal of the biologic film, with remnants observed. (d) SEM image taken following treatment for Group B–implantoplasty. Results show complete removal of the biologic film. The rough surface was removed, and the pure titanium is exposed.

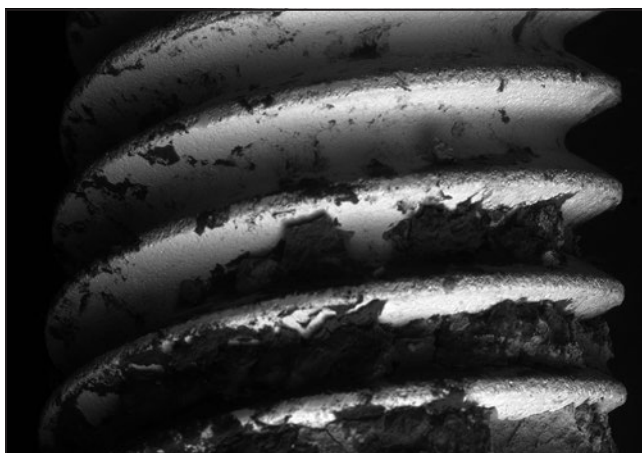


Fig 5 SEM image taken following treatment for Group C–laser. Results show some removal of the biologic film, with remnants observed.

modalities, verify via SEM, and re-implant them in the same host defect. The healing should be observed over a period of time, with a histologic analysis of sectioned blocks. This experiment would be very difficult to complete but would be able to further the understanding of what constitutes effective treatment of peri-implantitis.

There are limitations to the present study. The small sample size limits generalizability of the results. Additionally, three types of implants with different surfaces were used in the testing; although these three surfaces are widely used by clinicians, it is possible that differing surface characteristics were a factor in treatment efficacy and may have influenced the test results. For Group B (mechanical debridement), glycine and erythritol were not available at the time of the experiments, and further investigation using these tools could

be of value. Finally, this study only examined removal of the biologic debris from the implant surface and not the vitality of the biofilm.

Conclusions

In a pilot study examining *ex vivo* failed implants, a variety of treatment options were tested and evaluated for removal of biologic debris, which could approximate potential treatment of peri-implantitis. All of the chemical agents used were unable to remove the biologic debris from the implant surface. Partial removal was achieved with airborne-particle abrasion, titanium brush, and Er:YAG laser. Implantoplasty showed disturbance and removal of the biologic debris occupying infected implant surfaces. Implantoplasty may be a superior method of removing biologic debris from implant surfaces and potentially a more effective treatment for peri-implantitis, though further confirmatory studies are needed.

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References

- Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *J Periodontol* 2018;89(suppl 1):s267–s290.
- Strooker H, Rohn S, Van Winkelhoff AJ. Clinical and microbiologic effects of chemical versus mechanical cleansing in professional supportive implant therapy. *Int J Oral Maxillofac Implants* 1998;13:845–850.
- Leonhardt A, Dahlén G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. *J Periodontol* 2003;74:1415–1422.
- Gustumhaugen E, Lönn-Stensrud J, Scheie AA, Lyngstadaas SP, Ekfeldt A, Tøxt-Lamolle S. Effect of chemical and mechanical debridement techniques on bacterial re-growth on rough titanium surfaces: An *in vitro* study. *Clin Oral Implants Res* 2014;25:707–713.
- Froum SJ, Rosen PS, Wang WC, Froum SH, Vinayak S. Retrospective evaluation of factors related to the outcomes of regenerative therapy for implants affected by peri-implantitis. *Int J Periodontics Restorative Dent* 2018;38:181–187.
- Renvert S, Roos-Jansåker AM, Claffey N. Non-surgical treatment of peri-implant mucositis and peri-implantitis: A literature review. *J Clin Periodontol* 2008;35(suppl 8):s305–s315.
- de Waal YC, Raghoobar GM, Meijer HJ, Winkel EG, van Winkelhoff AJ. Implant decontamination with 2% chlorhexidine during surgical peri-implantitis treatment: A randomized, double-blind, controlled trial. *Clin Oral Implants Res* 2015;26:1015–1023.
- Mellado-Valero A, Buitrago-Vera P, Solá-Ruiz MF, Ferrer-García JC. Decontamination of dental implant surface in peri-implantitis treatment: A literature review. *Med Oral Patol Oral Cir Bucal* 2013;18:e869–e876.
- 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.
- 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.
- Tastepe CS, van Waas R, Liu Y, Wismeijer D. Air powder abrasive treatment as an implant surface cleaning method: A literature review. *Int J Oral Maxillofac Implants* 2012;27:1461–1473.
- Davies JM, Campbell LA. Fatal air embolism during dental implant surgery: A report of three cases. *Can J Anaesth* 1990;37:112–121.
- Magni G, Imperiale C, Rosa G, Favaro R. Nonfatal cerebral air embolism after dental surgery. *Anesth Analg* 2008;106:249–251.
- 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.
- John G, Becker J, Schwarz F. Rotating titanium brush for plaque removal from rough titanium surfaces—An *in vitro* study. *Clin Oral Implants Res* 2014;25:838–842.
- Sousa V, Mardas N, Spratt D, Boniface D, Dard M, Donos N. Experimental models for contamination of titanium surfaces and disinfection protocols. *Clin Oral Implants Res* 2016;27:1233–1242.
- Ramanauskaitė A, Daugela P, Faria de Almeida R, Saulacic N. Surgical non-regenerative treatments for peri-implantitis: A systematic review. *J Oral Maxillofac Res* 2016;7:e14.
- Romeo E, Lops D, Chiapasco M, Ghisolfi M, Vogel G. Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part II: Radiographic outcome. *Clin Oral Implants Res* 2007;18:179–187.
- Chan HL, Oh WS, Ong HS, et al. Impact of implantoplasty on strength of the implant-abutment complex. *Int J Oral Maxillofac Implants* 2013;28:1530–1535.
- Haas R, Dörtbudak O, Mensdorff-Pouilly N, Mailath G. Elimination of bacteria on different implant surfaces through photosensitization and soft laser. An *in vitro* study. *Clin Oral Implants Res* 1997;8:249–254.
- Kreisler M, Kohnen W, Marinello C, et al. Bactericidal effect of the Er:YAG laser on dental implant surfaces: An *in vitro* study. *J Periodontol* 2002;73:1292–1298.
- Subramani K, Wismeijer D. Decontamination of titanium implant surface and re-osseointegration to treat peri-implantitis: A literature review. *Int J Oral Maxillofac Implants* 2012;27:1043–1054.
- Keller T, Brinkmann T. Proposed guidance for carryover studies, based on elementary equivalence testing techniques. *Clin Lab* 2014;60:1153–1161.
- Htet M, Madi M, Zakaria O, et al. Decontamination of anodized implant surface with different modalities for peri-implantitis treatment: Lasers and mechanical debridement with citric acid. *J Periodontol* 2016;87:953–961.