Journal of Dental Sciences 17 (2022) 891–896

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

Effects of implant surface mechanical instrumentation methods on peri-implantitis: An *in vitro* study using a circumferential bone defect model

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Received 31 July 2021; Final revision received 20 August 2021
Available online 14 September 2021

KEYWORDS
Debridement;
Decontamination;
Implant;
Peri-implantitis

Abstract *Background/purpose:* Although several mechanical and chemical debridement techniques have been reported for the management of peri-implantitis, there is no consensus on the most effective method at present. This *in vitro* study aimed to examine the effects of different mechanical instrumentation techniques on the debridement of hard calcified materials, which are present on the implant surface, as well as the effect of the defect morphology.
Materials and methods: From a total of 15 implants, five each were assigned to one of three decontamination groups (Rotary titanium brush [Ti], tricalcium phosphate air powder abrasive treatment [Air], and titanium ultrasonic scaler [US] groups); the exposed hydroxyapatite (HA)-coated portion was divided into three 1-mm sections (coronal, middle, and apical). The residual-HA of each portion was measured using a digital microscope.
Results: The overall percentage of residual HA coating was significantly lower in the US group than in the Ti or Air groups ($p < 0.01$). The percentage of residual HA in the coronal portion was significantly lower in the Ti and US groups than in the Air group ($p < 0.05$ and $p < 0.01$, respectively). The percentage of residual HA in the middle portion was significantly lower in the US group than in the Air group ($p < 0.01$). The percentage of residual HA in the apical portion was significantly lower in the Ti group than in the Air or US groups ($p < 0.01$).

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https://doi.org/10.1016/j.jds.2021.08.018

Conclusion: Ti and US were more effective for shallow defects, whereas US was more effective for deeper defects.

Introduction

Peri-implantitis refers to the inflammation of the peri-implant tissue following osseointegration and is accompanied by bone destruction. It has a major impact on the long-term outcome of the dental implant and is a serious condition that triggers the exposure of the implant surface in the event of marked bone resorption.[1,2] The reported incidence varies owing to differences in the diagnostic criteria; however, a 2018 systematic review found that the frequency of peri-implantitis increases over time following superstructure placement, with an incidence rate of 0.4% and 43.9% within three and five years, respectively.[3]

Non-surgical methods (such as mechanical debridement and systemic administration of antibiotics) for the management of peri-implant mucositis reportedly resolve the inflammation and somewhat reduce the pocket depth.[4] However, non-surgical treatment alone elicits minimal effects on peri-implantitis. Although surgical treatment may be somewhat effective, the degree of efficacy varies depending on the site and morphology of the bone defect and superstructure. According to previous systematic reviews, even if an augmentative technique is used, re-osseointegration of the implant and bone is extremely difficult.[5,6] As described in previous studies, the physical properties of implant surfaces and thread shapes,[7,8] as well as clinical considerations, such as the angle of the mechanical instruments and its accessibility to the pocket-depth and the peri-implant bone defect pattern (vertical/horizontal),[9] greatly hinder implant surface debridement.[10]

Debridement and decontamination of the implant surface in peri-implantitis is performed using mechanical or chemical methods. The mechanical methods include air powder abrasive treatment, implantoplasty using a diamond bur or other types of burs, debridement with a titanium or plastic curette, or an ultrasonic device, a rotary titanium brush, and an erbium-doped yttrium aluminium garnet (Er:YAG) laser device. Implantoplasty removes the implant thread itself; therefore, the contaminated surface is certainly eliminated; however, the implant wall becomes thinner, which can compromise the mechanical property of the implant and may be associated with implant fracture. Air powder abrasive treatment can reach the thread-bottom area; however, the direction of abrasion is specifically limited toward the apical part of the implant, and decontamination may remain incomplete. An ultrasonic device can effectively reach the contaminated implant surface, even inside a narrow bone defect, if the tip of the instrument is properly designed. Similarly, a rotary titanium brush can reach the thread-bottom area; however, due to the diameter of the brush, it could be difficult to reach the apical part of the implant inside a narrow bone defect. The chemical methods include the use of saline solution, ethylenediaminetetraacetic acid, citric acid, and chlorhexidine. These methods have been used, both alone and in combination, during the surgical management of peri-implantitis.[11,12] Prior studies on the effects of mechanical instrumentation include *in vitro* assessments with oil-based ink[13–16] and *ex vitro* assessments with plaque and other dental biofilms.[17–20] Many studies have been conducted on horizontal bone defects (Class II), which are favorable for instrument accessibility.[7,21,22] However, no study has examined the effects of debriding hard, calcified material from the implant surface in a three-dimensional bone defect model (circumferential defect; Class Ie). Moreover, there is presently no consensus regarding the most effective method of debridement.[23]

Therefore, the present study aimed to evaluate the effectiveness of mechanical debridement methods typically used in daily clinical practice for the surface of hydroxyapatite-coated dental implants. Here, hydroxyapatite coating was regarded as a simulation of contaminated calculi. Additionally, it aimed to examine the effects of bone defect morphology on debridement in a circumferential bone defect model.

Materials and methods

Implant placement and defect model

This study followed the methodology described by Sahrmann et al.,[14] Wei et al.,[15] and Matsubara et al.[16] We used 15 implants (hydroxyapatite (HA)-coated, POI φ4.2 mm, 12 mm: Kyocera Corporation, Kyoto, Japan) in this study. The HA-coated portion (adhesion strength : 15Mpa) was used for the evaluation of debridement of the hard material.

Improved dental stone (New Fujirock; GC Corporation, Tokyo, Japan) was used to prepare bone defect models, as shown in Fig. 1. The implant body was stabilized after 3 mm of the HA-coated portion was exposed in a vertical direction. These bone defects were morphologically identical to Class Ie bone defects, the type of bone resorption most frequently observed in peri-implantitis, as shown in a study by Schwarz et al.[24]

Debridement groups

We created three decontamination groups comprising five implants, respectively, and these groups were compared to the control group (original surface). The debridement groups, based on the methods used, were as follows (Fig. 2):

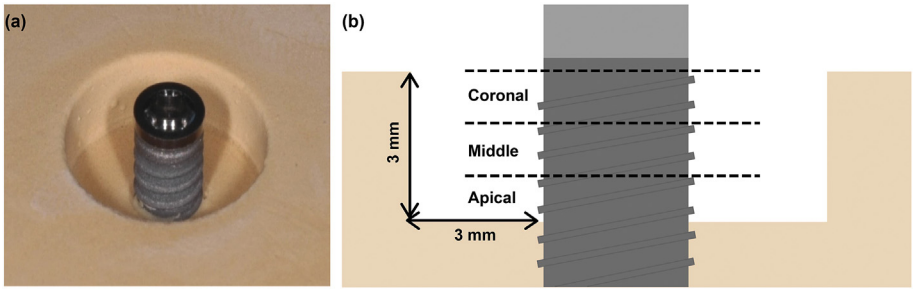

Figure 1 Implant placement and defect model. (a) Implant placement and preparation of defect model; (b) Diagram of bone defect model.

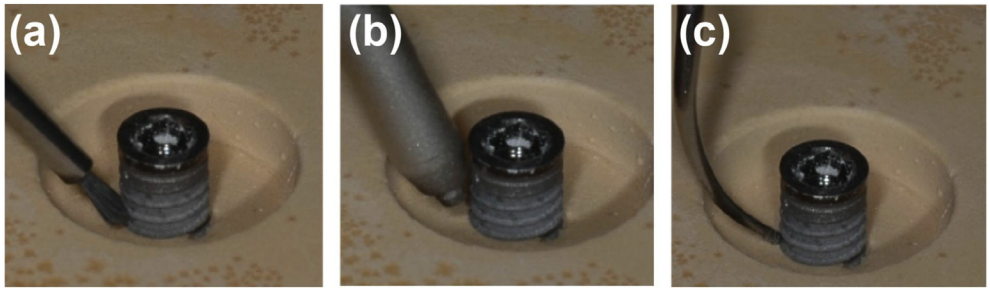

Figure 2 Different debridement groups. (a) Titanium brush (Ti); (b) β-tricalcium phosphate air abrasive (Air); (c) Titanium ultrasonic scaler tip (US).

- Ti: Rotary titanium brush, 3000 rpm (Titan Brush; 0.09 mm, Kyocera Corporation, Kyoto, Japan).
- Air: Air powder abrasion with tricalcium phosphate air abrasive (β-powder; particle size 40 μm, BrainBase Corporation, Tokyo, Japan) used at a distance of 1–2 mm from the implant surface.
- US: Titanium ultrasonic scaler, 0.4 W (PI tip: Osada, Tokyo, Japan).

These methods were applied on the implant threads for 5 min to evaluate the effectiveness and efficiency of the debridement.

The implant surface was debrided by an investigator experienced in using each method to treat peri-implantitis in clinical practice.

Analysis and measurement of the implant surface

A digital microscope (VHX-S50, Keyence Corporation, Osaka, Japan) was used to analyze the removal of the HA coating from the implant body surface.

As shown in Fig. 1b, the exposed HA-coated portion was divided into three 1-mm parts as follows: coronal, middle, and apical portions. Bone defects with a depth of 3 mm were classified into three groups of 1 mm each as follows: coronal, middle, and apical portions.

To evaluate the effect of three-dimensional debridement, two sides, 180° from one other on the implant surface, were examined with a digital microscope according to the method described by Sharmann et al.[15] and Steiger-Ronay et al.[8] Briefly, we took pictures of the debrided implant surface from two opposite directions and calculated the area of HA coating removed from the total implant surface in a two-dimensional aspect using an image analyzing software.

The residual HA was evaluated by a blinded examiner who observed the implant surface using a digital microscope and performed the measurements on one side and the opposite aspect (180° around) of the implant surface using a software (ImageJ ver.1.45; Wayne Rasband, NIH, Bethesda, MD, USA). The measurements were performed three times, and the average was defined as the residual HA (%).

Statistical analysis

Means and standard deviations of the percentages of the residual HA were calculated. Statistical processing differences between the three different instrumentation techniques were analyzed using nonparametric two-way ANOVA with Bonferroni correction. Statistical analyses were performed with PASW Statistics 18.0 (SPSS Japan Inc., Tokyo, Japan), with the level of significance defined at $p = 0.05$.

Results

Table 1 and Fig. 3 show the residual HA in each group. Fig. 4 presents images of differences in the residual HA portions following decontamination.

Differences in residual hydroxyapatite (overall)

Percentages of residual HA portions in the Ti, Air, and US groups were 16.0 ± 2.5%, 15.4 ± 2.8%, and 9.5 ± 1.7%, respectively. Thus, the percentage of residual HA coating

Table 1 Residual hydroxyapatite (HA)-coated portions (%) in each group.

	Residual HA (%)			
	Coronal	Middle	Apical	All
Ti	4.1 ± 4.0	15.0 ± 3.2	29.0 ± 3.4	16.0 ± 2.5
Air	12.2 ± 2.9	16.8 ± 3.1	18.8 ± 0.9	15.4 ± 2.8
US	0.9 ± 0.8	11.7 ± 1.4	13.0 ± 2.0	9.5 ± 1.7

Ti, Titanium brush; Air, β-tricalcium phosphate air abrasive; US, Titanium ultrasonic scaler tip.

was significantly lower in the US group than in the remaining two groups ($p < 0.01$).

Differences in residual hydroxyapatite (coronal)

Percentages of residual HA portions in the Ti, Air, and US groups were 4.1 ± 4.0%, 12.2 ± 2.9%, and 0.9 ± 0.8%, respectively. Thus, the percentage of residual HA coating was significantly lower in the Ti and US groups than in the Air group ($p < 0.05$ and $p < 0.01$, respectively).

Differences in residual hydroxyapatite (middle)

Percentages of residual HA portions in the Ti, Air, and US groups were 15.0 ± 3.2%, 16.8 ± 3.1%, and 11.7 ± 1.4%, respectively. Thus, the percentage of residual HA coating was significantly lower in the Air group than in the US group ($p < 0.01$).

Differences in residual hydroxyapatite (apical)

Percentages of residual HA portions in the Ti, Air, and US groups were 29.0 ± 3.4%, 18.8 ± 0.9%, and 13.0 ± 2.0%, respectively. Thus, residual HA coating was high in all the groups. Specifically, the percentage of residual HA coating was significantly higher in the Ti group than in the Air and US groups ($p < 0.01$). In addition, residual HA was significantly lower in the US than in the other two groups ($p < 0.01$).

Discussion

The present study evaluated the *in vitro* effects of three different methods of implant surface debridement for the removal of hard, calcified materials and examined the effect of bone defect morphology on debridement in a

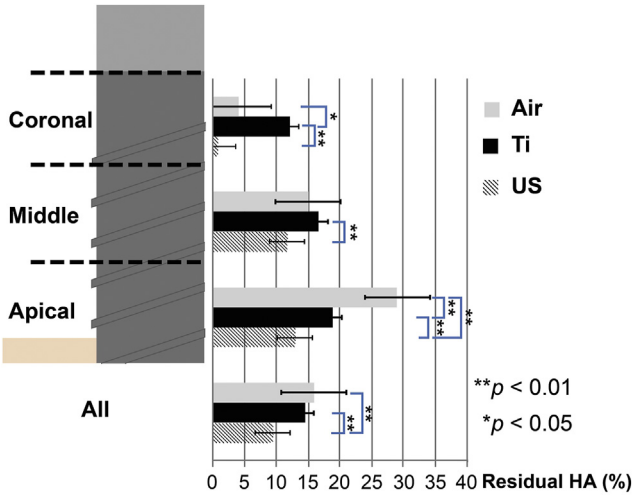

Figure 4 Differences in residual hydroxyapatite following debridement (coronal, middle, and apical portions).

circumferential bone defect model. In the bone defect model used in the present study, the relative effectiveness of the debridement methods was as follows: (i) overall, US was superior to Ti and Air; (ii) in the coronal portion, Ti and US were superior to air; (iii) in the middle portion, US was superior to Ti, which in turn was superior to Air; and (iv) in the apical portion, US was superior to Ti, which in turn was superior to Air.

A digital microscope was used to assess and analyze the effect of debridement of hard, calcified materials by subjecting the HA-coated portions of the implant surfaces to mechanical instrumentation. The HA-coated implant surfaces were analyzed in this study because the HA coating has a white color that enables visual assessment of the effects of mechanical debridement, as it is difficult to distinguish the differences between the treated and untreated sections using a digital microscope in rough surface implants (such as those subjected to titanium blasting and acid etching). The HA-coated implants used in the present study had a strength of attachment of 15 MPa. In a previous study examining mechanical biofilm removal from the oral biofilm-coated dentin, the bond strength of the oral biofilm was 12–18 MPa.[25] This value is similar to that shown in the present study, i.e., 15 Mpa.

However, since this is a limited study wherein HA was regarded as biofilm or calculus, it is necessary to study the actual strength of attachment of biofilm or calculus on titanium.

Although various mechanical debridement methods for peri-implantitis have been devised and applied clinically,

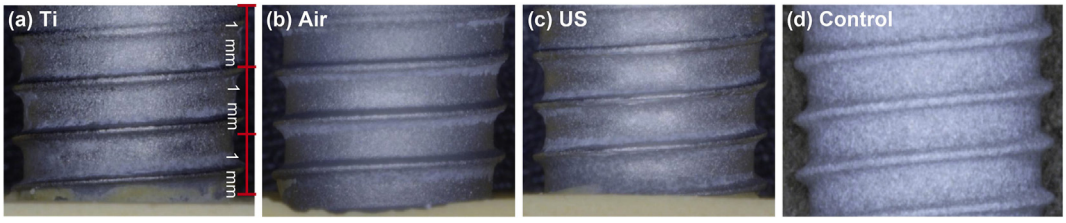

Figure 3 Post-debridement changes in implant surfaces.

an effective mechanical debridement method has not yet been established[26] since peri-implantitis presents with a wide variety of bone defect morphologies, implant surface properties, and implant surface shapes, indicating insufficient complete mechanical debridement.[6] Furthermore, in a narrative review, Froum et al.[27] reported that the removal of the prosthetic superstructure facilitates surgical access to the implant surface.

In this study, a circumferential defect model specific to peri-implantitis was created, and the mechanical debridement effects in the coronal, middle, and apical portions of the bone defects were compared. Consequently, the use of an ultrasonic device was found to be effective.

This study used a bone defect measuring 3 mm in width, which is relatively wide compared to the clinical situation of peri-implantitis encountered in daily practice. Even with a defect of this size, the air powder abrasion seemed to have limited access to the residual coating at the thread-bottom surface, as observed in Fig. 3b. In contrast, although the titanium brush appeared to have optimal access in the bone defect model, the debridement effectiveness declined as the area became apical (Fig. 2). This probably implies that to effectively debride the titanium brush, the brush should be as perpendicular to the implant surface as possible, and the effectiveness of debridement reduces as the brush tip is inclined toward the implant surface.

In an *in vitro* study, Sahrmann et al.[13] assessed debridement using an air-flow device in models of peri-implantitis with different bone defects and reported that the effect of debridement diminished as the bone defects (angulations) decreased in size. Moreover, in studies assessing debridement using instruments in three types of vertical bone defect models (30°, 60°, and 90°), air powder abrasion was found to be superior to an ultrasonic scaler, which was in turn superior to curettes.[28–30] However, in all these studies, the implant surfaces were stained using indelible ink, and the debridement targets were not calcified; thus, the conditions in these studies facilitated physical debridement. In contrast, Sirinirund et al.[21] coated implant bodies with artificial calculus and compared them with mechanical debridement methods; ultrasonic tips and air powder abrasion were observed to be the most effective methods, subsequently followed by titanium brushes and curettes. In addition, the removal time was the shortest with ultrasonic tips, which were reported to be the most efficient mechanical debridement instrument. However, this study used instruments to implant bodies at an angle of 90° and, thus, did not assess the effects on different bone defects.

In an *ex vivo* study, Al-Hashedi et al.[17] used scanning electron microscopy and X-ray photoelectron spectroscopy to analyze and compare the debridement of oral biofilms using four different decontamination instruments and found that titanium brushes were more effective than curettes and Er:YAG lasers in debriding titanium implant surfaces. Similarly, in a scanning electron microscopic analysis by Otsuki et al.,[18] five methods for decontaminating oral biofilms on rough and machined surface implants were compared, and the use of saline-soaked gauze and a rotary stainless-steel instrument was reported to be the most effective methods, whereas air abrasion was not particularly effective. However, the abovementioned studies used oral biofilms, which can be decontaminated relatively easily. In addition, since both studies performed decontamination outside the oral cavity, they did not simulate real-world clinical settings.

The design of this study is superior to other studies since the bone defect morphology was replicated into a clinically three-dimensional structure, the mechanical instrument was evaluated based on the depth of the defect, and the evaluation was performed using a hard calcified material. The results revealed that each portion of the bone defect, the coronal, middle, and apical portions, demonstrated different debridement effects. In addition, digital microscopic images showed differences in the debridement of the thread-top and the thread-upper and thread-bottom surfaces, which conceivably stem from differences in the accessibility of the instruments and the direction in which they were used.

A titanium brush is effective for sites that a brush can contact directly. The potent debridement effect in the coronal portion suggests that the titanium brush could contact nearly the entire surface in the coronal portion. However, this phenomenon also suggests that the limited instrumental access in the middle and apical portions made debridement of the thread-bottom area difficult. In a five-year prospective case series involving mechanical debridement using a titanium brush and chemical decontamination using hydrogen peroxide (3%) and chlorhexidine (0.2%) reported by La Monaca et al.,[30] the success rate at one year following surgery was 91%, which decreased to 59% at five years. The success rate may have decreased owing to insufficient mechanical debridement associated with bone defect morphology.

Air abrasive devices remove contaminants through physical contact via various microparticles sprayed with air pressure. Regarding the biofilm decontamination effect of air abrasive devices, Tastepe et al.[31] conducted an air powder abrasive treatment using various materials on titanium discs, which were contaminated intraorally and reported that calcium phosphate powder had the greatest decontamination effect. Therefore, tricalcium phosphate was used in this study. Experiments using artificial calculus. The shape of However, with air abrasive devices, the angle at which the air is sprayed onto the implant body greatly affects the percentage of residual contaminant; a previous study revealed that angles of 90° and 15° resulted in residual contaminant rates of 3% and 51%, respectively.[4] Thus, the poor effect of air abrasive devices in this study could be attributed to the restricted accessibility associated with the spray angle in our bone defect model, problems with spray time, and the fact that HA, rather than biofilm, was debrided.

The US demonstrated the greatest debridement in this study, a result identical to that observed by Sirinirund et al.,[21] who conducted the tip used in this study was designed for furcations. Therefore, the tip could contact nearly the entire surface of the bone defect model in this study, which could be the reason for the significant effectiveness of the US in debriding the coronal, middle, and apical portions of the HA coating.

This study had certain limitations; specifically, it focused on the effectiveness of mechanical debridement on a single vertical bone defect model. In clinical practice, peri-implantitis presents with diverse bone-defect morphologies, and it is necessary to consider the effects of instrument accessibility, instrument operation angle, and the shape of the implant surface body (for example,

microthreads). Therefore, debridement methods should be further evaluated in combination with microbiological investigations.

In conclusion, the results of the present *in vitro* study suggest that titanium brushes and ultrasonic scalers are effective for the debridement of shallow defects (near the bone crest), while ultrasonic scalers are more effective for the debridement of deeper defects ($\geq$1 mm) in the surgical treatment of peri-implantitis with horizontal and vertical defects.

Declaration of competing Interest

None.

Acknowledgements

We would like to express our gratitude to Ryota Kawamata for his work on the statistical analysis of data.

We would like to thank Editage (www.editage.com) for English language editing.

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