Received: 6 May 2022 | Accepted: 24 June 2022

DOI: 10.1111/clr.13991

ORIGINAL ARTICLE

CLINICAL ORAL IMPLANTS RESEARCH WILEY

In vitro effect of different implant decontamination methods in three intraosseous defect configurations

Fernando Luengo[1,2] | Javier Sanz-Esporrín[1,2] | Fernando Noguerol[1] | Ignacio Sanz-Martín[3] | Ignacio Sanz-Sánchez[1,2] | Mariano Sanz[1,2]

[1]Section of Periodontology, Faculty of Odontology, University Complutense, Madrid, Spain

[2]ETEP (Etiology and Therapy of Periodontal and Peri-implant Diseases) Research Group, University Complutense, Madrid, Spain

[3]Private practice Lausanne, Lausanne, Switzerland

Correspondence
Javier Sanz-Esporrín, Facultad de Odontologia – Periodoncia, Universidad Complutense de Madrid, Plaza Ramon y Cajal, 28040 Madrid, Spain.
Email: javier.sanz.esporrin@ucm.es

Abstract

Objectives: This in vitro investigation was aimed to evaluate the cleaning ability of four mechanical devices designed for decontaminating implant surfaces.

Material and methods: Ninety-six implants were coated with permanent ink and inserted into 3D-printed resin blocks simulating three different intraosseous defect configurations (types Ib, Ic, and Ie). The four tested mechanical decontamination devices (air-polishing with glycine powder, rotating titanium brush, polyetheretherketone [PEEK]-coated ultrasonic tip, and stainless steel ultrasonic tip) were randomly applied onto the 5 mm exposed implant surface. Standardized photographs were taken from a frontal perspective and with a 30° angle coronally and apically to the implant axis. The area with remnant ink on the implant surface was calculated.

Results: Although none of the groups achieved complete ink removal, air-polishing with glycine and titanium brushes demonstrated a higher cleaning ability when compared with ultrasonic devices either with standard or PEEK tips for all three defect configurations. For the three tested models, the best cleaning ability in all groups was shown on implant surfaces without facing an intraosseous wall. Titanium brush was the most effective when the intraosseous walls existed. Cleaning effectiveness diminished in the threads located in the apical third, especially when using air-polishing and ultrasonic devices.

Conclusions: Titanium brushes and air-polishing devices were more effective in removing artificial biofilm using this in vitro model, although their effectiveness was influenced by the presence of the intrabony component.

KEYWORDS
decontamination, dental implants, peri-implantitis, titanium

1 | INTRODUCTION

Dental implants have shown to be a safe and reliable treatment approach for the rehabilitation of partial and full edentulous patients, demonstrating high long-term survival rates (Papaspyridakos et al., 2018). However, dental implants are not free from complications, and peri-implant diseases (peri-implant mucositis and peri-implantitis) are a frequent finding (Jung et al., 2012; Pjetursson et al., 2012).

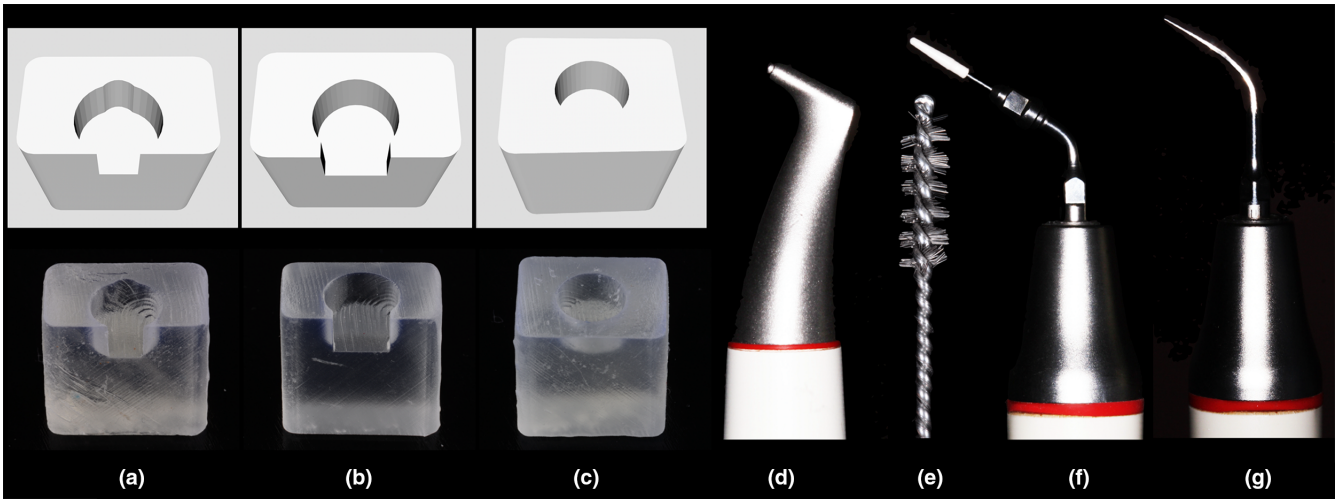

FIGURE 1 Virtual design of the defect models (a–c) and the decontamination methods used: air-abrasive device (d), titanium brush (e), PEEK ultrasonic tip (f), stainless steel ultrasonic tip (g).

Peri-implantitis is a pathological condition, characterized by inflammation in the peri-implant connective tissue and progressive loss of supporting bone (Schwarz et al., 2018). Its estimated prevalence ranges from 22 to 28% (Derks & Tomasi, 2015; Renvert, Lindahl, & Persson, 2018; Romandini et al., 2021) and clinically, this disease is characterized by the presence of clinical signs of inflammation, such as bleeding on probing with or without suppuration, increased probing depth over time compared to previous measurements, and the existence of progressive radiographic bone loss, what usually results in part of the implant surface exposed and, hence, more vulnerable to potential bacterial contamination (Renvert, Persson, Pirih, & Camargo, 2018).

Although it is well known that different risk indicators and risk factors may modulate the incidence of peri-implantitis (Heitz-Mayfield, 2008; Serino & Hultin, 2019), its etiology is infectious, caused by the accumulation of a biofilm on the implant/abutment surface what elicits an inflammatory response, which in some implants lead to bone loss (Daubert & Weinstein, 2019; Schou et al., 1992). Due to this fact, the main therapeutic goal in the treatment of peri-implantitis is to remove the biofilm and decontaminate the exposed implant surface (Mombelli & Lang, 1994) with the purpose of preventing further recolonization (Heitz-Mayfield & Mombelli, 2014). Despite the use of different physical and mechanical methods to remove the biofilm and decontaminate the affected implant surface, the nonsurgical treatment of peri-implantitis sites has demonstrated limited efficacy and seldom disease resolution (Figuero et al., 2014; Renvert et al., 2008), although recently, nonsurgical treatment strategies combining mechanical and chemical therapies have shown promising results that need to be confirmed by controlled clinical studies (Estefania-Fresco et al., 2019; Linares et al., 2019; Nart et al., 2020). The surgical treatment of peri-implantitis based on a thorough implant surface decontamination is currently the preferable treatment approach, although its efficacy may be influenced by the anatomy of the bony lesion and the ability of current decontamination methods to fully access the affected implant surface (Ramanauskaite et al., 2016).

When applied nonsurgically, the method of decontamination used may be influenced, beyond its inherent efficacy, by the presence of the prosthetic rehabilitation, the implant macroscopic design (size of the treads and interthread distance), the implant microsurface topography (roughness) (Sanz-Martin et al., 2021; Steiger-Ronay et al., 2017) and the operator experience and ability (de Waal et al., 2016; Ruhling et al., 2002). When applied surgically, the accessibility of the decontamination method to the implant surface will improve, although its relative efficacy may be influenced by the anatomy of the bony lesion (Claffey et al., 2008).

Two types of peri-implant osseous lesions have been defined as associated with peri-implantitis sites: intraosseous (Class I defects) and supracrestal (Class II defects). Within the intraosseous lesions, depending on the number of walls present and the morphology of the defect, five categories have been defined (Classes Ia-e) (Schwarz et al., 2007), which may influence the access of the different decontamination methods to remove the biofilm and calculus from the affected implant surfaces (Meyle, 2012; Subramani & Wismeijer, 2012). In fact, in vitro studies simulating crater-shaped intrabony peri-implantitis defects (Class Ie) have shown that depending on the angle of application of the decontamination method, its efficacy was significantly affected (Keim et al., 2019; Sahrmann et al., 2015; Sahrmann et al., 2021; Steiger-Ronay et al., 2017). However, our understanding on the impact of the defect anatomy in the relative efficacy of mechanical implant surface decontamination is still limited. It was, therefore, the objective of this in vitro study to determine the decontamination effectiveness of four types of mechanical instruments (ultrasonic devices with stainless steel or PEEK-coated tips, titanium brushes, and air-polishing devices) when systematically applied on three different defect configurations (types Ib, Ic, and Ie).

2 | MATERIAL AND METHODS

2.1 | In vitro model design

Blocks, of about 20×20×15 mm in dimension, were virtually designed (AutoCAD, Autodesk), based on the classification of peri-implant defects (Ib, Ic, and Ie,) as described by (Schwarz et al., 2007). Once designed, ninety-six blocks were 3D printed (Formlabs2, Formlabs) using gray resin material (Gray Resin, Formlabs) (Figure 1). Ninety-six 4-mm-diameter and 13-mm-length implants (Neodent® TitamaxTI, Institut Straumann AG) were used. The characteristics of this implant include a distance between threads of 0.6 mm and a sandblasted and acid-etched surface (Sa = 1,4–1,8 μm; Sz = 15 μm) (Neoporos®, Institut Straumann AG). Implants were submerged in a recipient with blue permanent ink (Staedtler® Lumocolor) fully covering the implant surface. Once dried for 48 h, the implants were inserted into the blocks mimicking peri-implant defects, with 5 mm of their surface exposed within the intraosseous defect (Figure 2). The procedures of the present study were carried out following the suggested recommendations on the need to standardize guidelines for in vitro studies (Krithikadatta et al., 2014) while these guidelines (CRIS Statement) are still under development. Ethics approval was not required for this in vitro study.

Four different decontamination methods commonly used in the treatment of peri-implantitis were selected:

- Air-polishing device using a 25 μm glycine powder and set at full power with irrigation (Air-Flow® system with Perio Prophylaxis Powder®, E.M.S. Electro Medical Systems) (Group 1: AF)
- Rotating brush with titanium bristles placed in a low-speed handpiece set at 800 rpm with irrigation (Straumann TiBrush®, Institut Straumann AG) (Group 2: TB)
- Polyetheretherketone (PEEK) coated ultrasonic tip, set at full power with irrigation (PI Instrument®, E.M.S. Electro Medical Systems; Nyon, Switzerland) (Group 3: PI)
- Stainless steel ultrasonic tip, set at full power with irrigation (PS1 tip, E.M.S. Electro Medical Systems) (Group 4: US)

The exposed surface of the implants within the blocks was treated with each decontamination device (24 implants per group) for 2 min by a single operator.

After this treatment, the implants were carefully removed from the resin block and placed in a purpose-made photographic stent consisting of a metallic structure with a contra-angle handpiece, which allowed the implant rotating 360°. The camera was mounted at 31 cm from the implant surface and standardized photographs were taken at frontal view (0°) and at 30° angulation from the longitudinal implant axis, thus allowing for coronal and apical views, as reported in previous similar in vitro studies (Sahrmann et al., 2013; Sahrmann et al., 2015; Steiger-Ronay et al., 2017). Photographs were also taken at the buccal, mesial, distal, and lingual sides of each implant.

All photographs were taken with a camera Nikon D90 (NIKON) using a lens Tamron Macro 90 mm (TAMRON) and a flash lighting system (YongNuo YN685 Flash, YONGNUO). The camera setting parameters were ISO 100, aperture f32, and exposure 1/250. Once all the photographs were digitalized and calibrated with an image software (Adobe Photoshop CC 2019, Adobe Inc), a 5 mm square

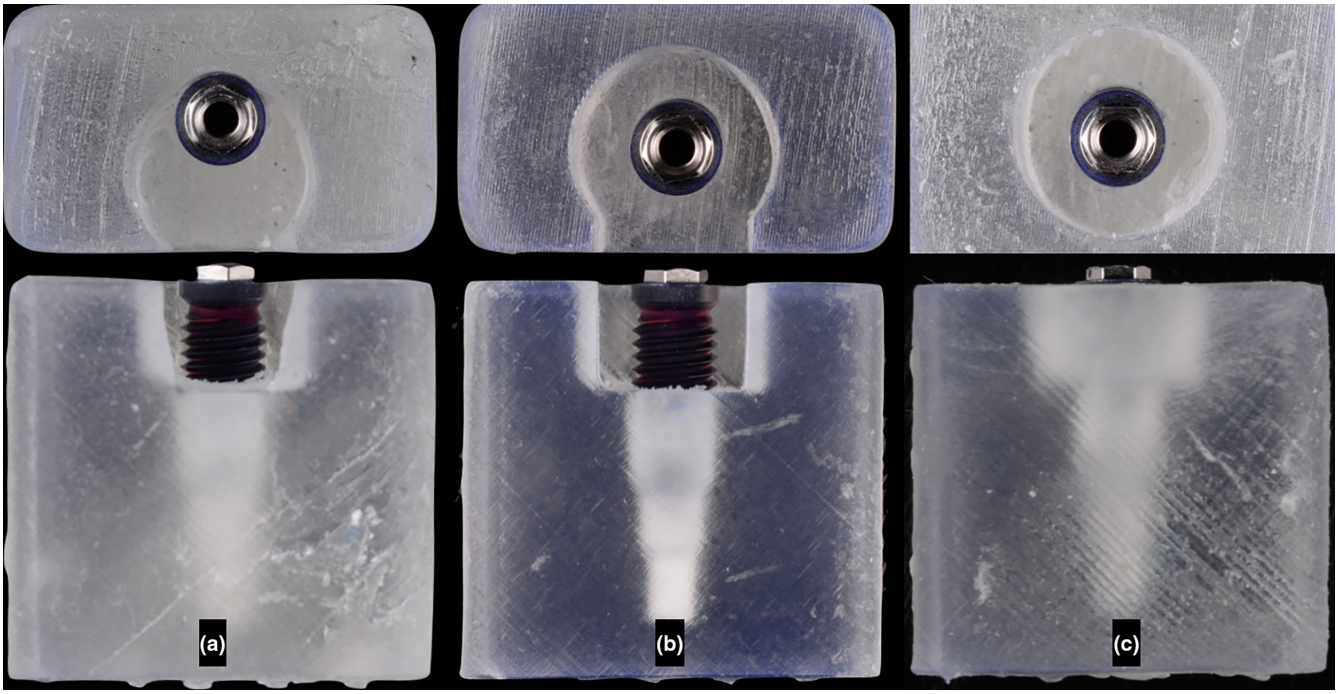

FIGURE 2 Dental implants inserted into the different defect configurations of the 3D-printed resin blocks.

area of interest was created delimitating the treated exposed surface (Figure 3), and the areas with remnant ink on the implant surface were detected and measured (Adobe Photoshop CC 2019, Adobe Inc) (Figure 4).

2.2 | Statistical analysis

Data were expressed as the percentage area of residual ink with respect to the total surface of interest measured. Normality of data distribution was tested using Kolmogorov–Smirnov and Shapiro–Wilk tests. Means and standard deviations of the percentages of the surface presenting residual ink were calculated. Bonferroni corrections were performed for multiple comparisons. The alpha error was set at 0.05. Differences between different defect sides and instruments were tested by the two-way ANOVA test. All the tests were calculated using the SPSS software (IBM Statistics V20.0, IBM).

3 | RESULTS

None of the treated surfaces demonstrated complete ink removal, however, the percentage of residual ink was different depending on the device used and the type of defect. In addition, the different implant surfaces (buccal, mesial, distal, and lingual) showed different percentages of ink removal in each type of defect. Table 1 depicts the relative effect of the different decontamination methods used according to the type of defect. Depending on the accessibility to the exposed implant surface on the different types of peri-implant defects, three scenarios were constructed and the relative effect of the tested decontamination methods was evaluated (Figure 5).

Scenario 1: Buccal dehiscence with direct vision and access to the implant surface (buccal surface of defects "Ib" and "Ic").

In this scenario, all cleaning devices demonstrated the highest decontamination activity. However, titanium brushes (90.86% ± 5.60 (Ib); 88.03% ± 8.11 (Ic)) and air-polishing (87.06% ± 2.79 (Ib); 88.66% ± 8.46 (Ic)) demonstrated the highest effect, being

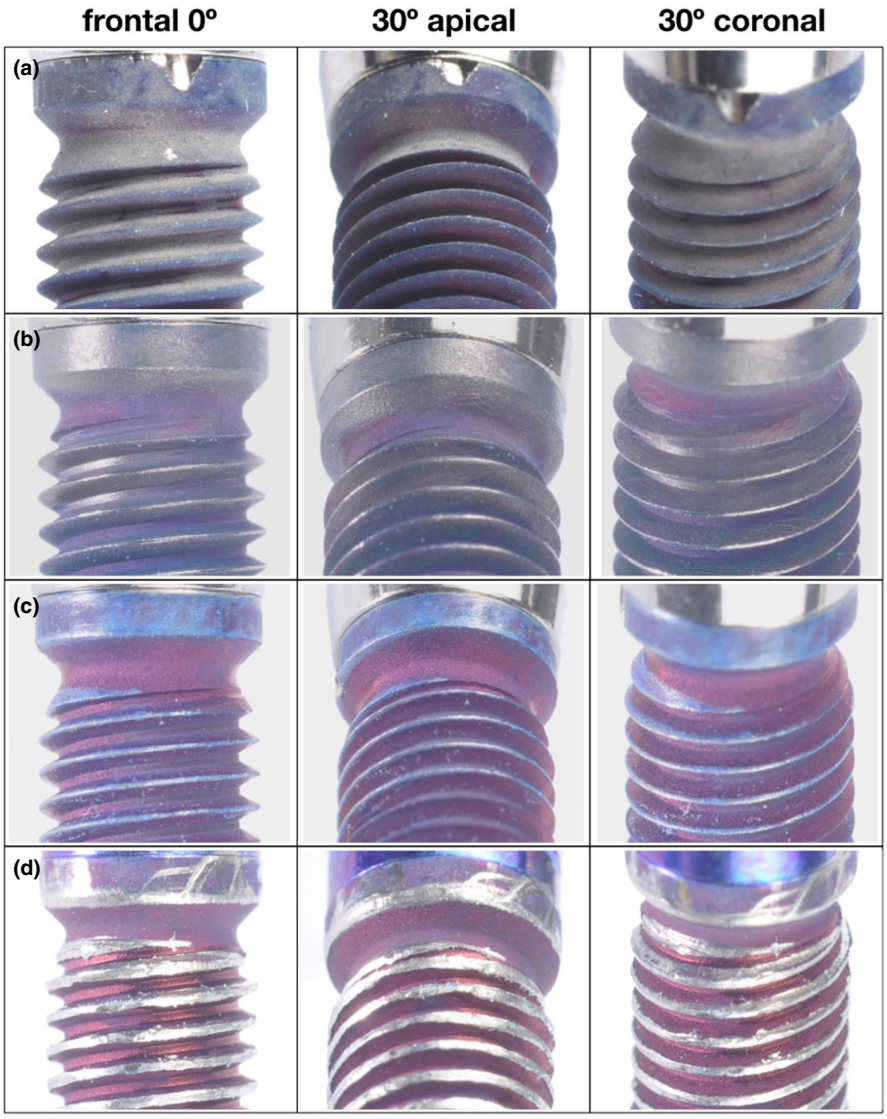

FIGURE 3 Picture samples from different points of view of the implants treated with different devices. AF group (a), TB group (b), PI group (c), US group (d).

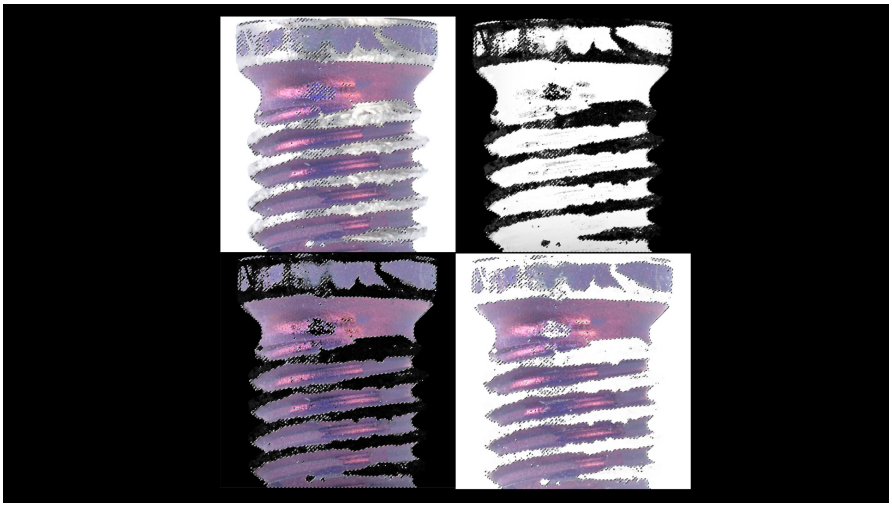

FIGURE 4 Digital evaluation of the remaining ink by isolating the stained areas after determining the region of interest.

TABLE 1 Residual ink of the different groups (mean ± SD) expressed in percentage, analyzed from a frontal view (0°) in buccal, mesial, and distal sides on simulated defects types B, C, and E

		BUCCAL	MESIAL	DISTAL	LINGUAL
DEFECT "B"	AF	12.94 ± 2.79	14.04 ± 4.09	13.50 ± 5.47	
	TB	9.14 ± 5.60	10.91 ± 3.34	12.84 ± 4.57	
	PI	50.61 ± 7.74	52.75 ± 9.63	58.15 ± 5.12	
	US	42.62 ± 7.55	57.74 ± 5.89	48.17 ± 3.18	
	AF-TB	3.80	3.13	0.66	
	AF-PI	−37.67*	−38.70*	−44.64*	
	AF-US	−29.68*	−43.69*	−34.66*	
	TB-PI	−41.46*	−41.84*	−45.31*	
	TB-US	−33.47*	−46.83*	−35.32*	
	PI-US	7.99	−4.99	9.98	
DEFECT "C"	AF	11.34 ± 8.46	7.74 ± 4.98	7.24 ± 2.58	8.43 ± 3.00
	TB	11.97 ± 8.11	13.05 ± 7.81	15.74 ± 8.19	18.07 ± 6.18
	PI	56.69 ± 6.67	63.53 ± 10.39	67.99 ± 4.53	74.76 ± 6.45
	US	46.45 ± 16.27	60.57 ± 5.73	61.34 ± 7.49	65.30 ± 9.32
	AF-TB	−0.63	−5.31	−8.50	−9.64
	AF-PI	−45.35*	−55.79*	−60.74*	−66.33*
	AF-US	−35.11*	−52.84*	−54.10*	−56.87*
	TB-PI	−44.72*	−50.48*	−52.24*	−56.68*
	TB-US	−34.48*	−47.53*	−45.59*	−47.22*
	PI-US	10.24	2.96	6.65	9.46
DEFECT "E"	AF	12.00 ± 7.14	11.37 ± 7.14	11.01 ± 6.02	12.50 ± 5.45
	TB	9.71 ± 5.86	12.68 ± 10.29	11.10 ± 8.49	9.99 ± 6.71
	PI	65.13 ± 30.56	66.37 ± 31.27	68.70 ± 28.88	68.44 ± 29.65
	US	63.70 ± 4.76	61.30 ± 6.77	64.04 ± 5.62	63.25 ± 2.78
	AF-TB	2.29	−1.31	−0.08	2.51
	AF-PI	−53.13*	−55.00*	−57.69*	−55.94*
	AF-US	−51.70*	−49.92*	−53.02*	−50.76*
	TB-PI	−55.42*	−53.69*	−57.61*	−58.45*
	TB-US	−53.99*	−48.61*	−52.94*	−53.27*
	PI-US	1.43	5.08	4.67	5.19

Note: Differences between groups are also presented. *Comparison between groups on each side (ANOVA test) with $p < .05$.

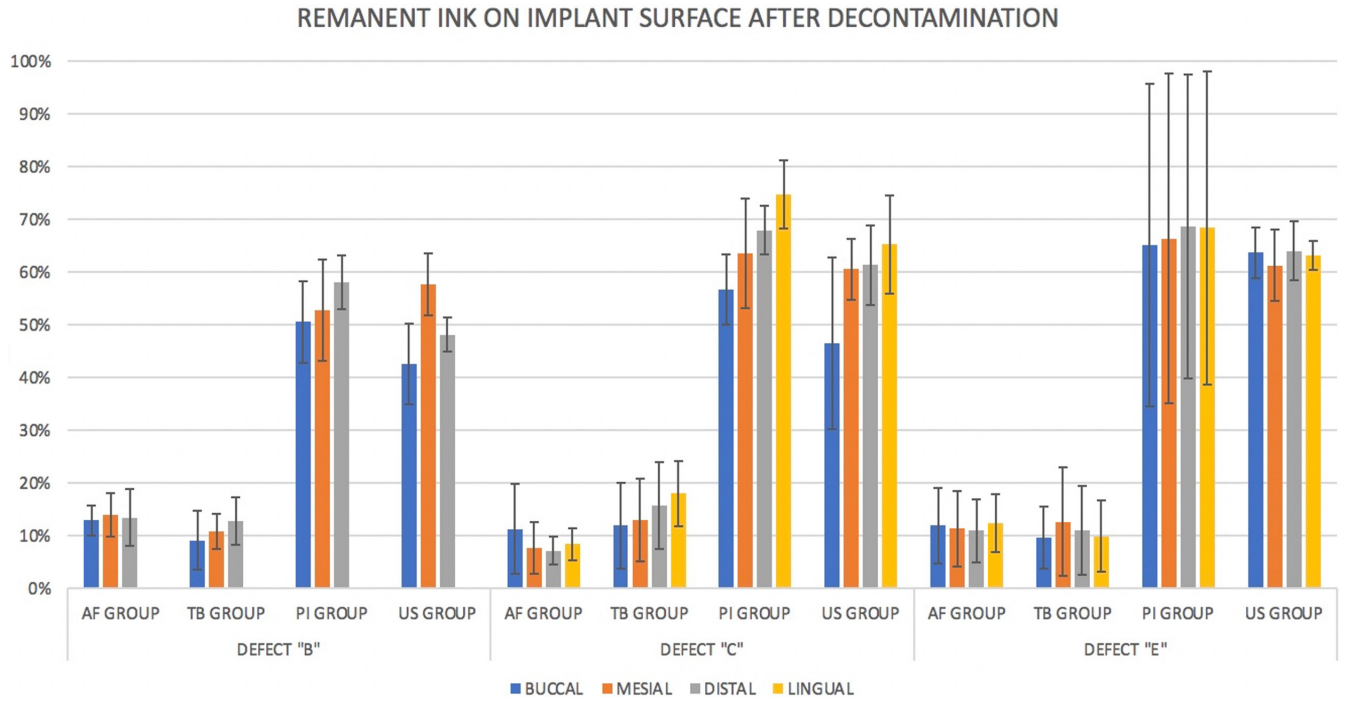

FIGURE 5 Comparison by groups and defect types of remnant ink on implant surface after decontamination.

significantly better ($p < 0.001$) than ultrasonic devices with either stainless steel (57.38% ± 7.55 (Ib); 53.55% ± 16.27 (Ic)) or with PEEK tips (49.39% ± 7.74 (Ib); 43.31% ± 6.67 (Ic)).

The analysis from the coronal view showed similar results for AF and TB, both significantly better than PI and US ($p < .001$) (Table 2). From the apical view, the efficacy of AF diminished, being significantly lower than TB ($p = .038$), which was significantly more efficient than both PI ($p < .001$) and US ($p < .001$) (Table 3).

Scenario 2: Buccal dehiscence with frontal access to the interproximal surfaces (mesial and distal surfaces of defects "Ib" and "Ic").

TB and AF demonstrated similar activity and both significantly better compared with US and PI ($p < .001$).

In this scenario, when the access to the interproximal walls of the defect was narrower (type b defect), the TB was the most efficient (89.09% ± 3.34 (mesial); 87.16% ± 4.57 (distal)). Similar to *scenario 1* the apical analysis of the implant surface depicted a lesser effect for AF, which left significantly more residual ink than TB on both mesial ($p = .019$) and distal ($p = .039$) sides. Also TB was significantly superior compared to PI ($p < .001$) and US ($p < .001$) (Table 3).

When the access to the interproximal space was wider (type c defect), the AF group demonstrated the highest decontamination effect (92.26% ± 4.98 (mesial); 92.76% ± 2.58 (distal)). Both AF and TB demonstrated significantly higher activity when compared to PI and US ($p < .001$).

Scenario 3: Vertical access when the implant surface was facing a defect wall (lingual surface of defect type "c" and all surfaces of defect type "e")

In the frontal and coronal analyses, AF and TB performed similarly in both types of defects, with significantly better activity ($p < .001$) when compared to US and PI. In the apical analysis, TB demonstrated a significantly better effect compared with PI and US in both types of defects ($p < .001$) and a significantly better effect when compared to AF in type "c" defect ($p < .001$).

4 | DISCUSSION

The results from the present in vitro study clearly show that both the defect configuration and the method of mechanical debridement significantly influenced the relative activity to decontaminate the stained implant surfaces. Although no single method achieved complete removal of the ink, titanium brushes (TB) and, air-polishing devices (AF group) demonstrated the best cleaning ability, in comparison with steel or peek ultrasonic tips (US and PI group) in all defect types. The best results were achieved when the access to the implant surface was direct (no presence of defect wall) and in these areas, differences among decontamination methods were small. During the surgical treatment of peri-implantitis sites, when the presence of bony walls may compromise the access to the exposed implant surfaces, this intraosseous component may be eliminated by removing the bony walls as it is done in resective surgery or reconstructed as it is aimed in regenerative surgery. However, in both surgical approaches surface decontamination is a determinant factor in the outcome (Chan et al., 2014; Renvert et al., 2012).

In this study, the presence of defect walls, as shown in the results from the different scenarios, clearly influenced the effect of the used mechanical debridement method. Previous "in vitro" studies have mainly used supracrestal or circumferential defects with angulations between 30° and 90°, where the access to the implant surface is similar to all areas of the implant, and hence, these models

TABLE 2 Residual ink of the different groups (mean ± SD) expressed in percentage, analyzed from a 30° coronal point of view in buccal, mesial, and distal sides on simulated defects types B, C, and E

		BUCCAL	MESIAL	DISTAL	LINGUAL
DEFECT "B"	AF	12.28 ± 5.63	12.43 ± 7.94	15.85 ± 6.09	
	TB	12.85 ± 4.58	13.26 ± 4.62	12.69 ± 6.76	
	PI	48.36 ± 10.11	49.49 ± 12.01	53.29 ± 9.83	
	US	33.25 ± 7.63	42.65 ± 7.71	40.62 ± 11.95	
	AF-TB	−0.58	−0.83	3.15	
	AF-PI	−36.09*	−37.06*	−37.45*	
	AF-US	−20.98*	−30.21*	−24.77*	
	TB-PI	−35.51*	−36.23*	−40.6*	
	TB-US	−20.4*	−29.39*	−27.93*	
	PI-US	15.11*	6.84	12.67	
DEFECT "C"	AF	10.72 ± 5.62	11.56 ± 8.42	9.96 ± 6.45	13.74 ± 7.07
	TB	11.43 ± 6.55	11.43 ± 7.3	11.75 ± 4.4	12.79 ± 5.36
	PI	52.51 ± 13.06	53.62 ± 6.74	58.64 ± 6.9	64.05 ± 7.04
	US	49.03 ± 16.8	63.95 ± 8.36	61.58 ± 7.68	72.68 ± 7.39
	AF-TB	−0.71	0.13	−1.79	0.95
	AF-PI	−41.79*	−42.07*	−48.68*	−50.31*
	AF-US	−38.31*	−52.39*	−51.62*	−58.94*
	TB-PI	−41.08*	−42.2*	−46.89*	−51.26*
	TB-US	−37.6*	−52.52*	−49.83*	−59.89*
	PI-US	3.48	−10.32	−2.94	−8.63
DEFECT "E"	AF	6.69 ± 3.5	9.09 ± 6.78	9.41 ± 5.03	15.16 ± 11.9
	TB	9.16 ± 4.2	9.36 ± 2.23	10.27 ± 2.76	8.07 ± 2.68
	PI	65.45 ± 5.25	64.32 ± 3.84	65.67 ± 8.3	67.41 ± 4.28
	US	57.71 ± 6.53	56.48 ± 10.37	57.94 ± 6.47	56.84 ± 8.27
	AF-TB	−2.47	−0.28	−0.86	7.08
	AF-PI	−58.76*	−55.23*	−56.26*	−52.25*
	AF-US	−51.02*	−47.4*	−48.53*	−41.68*
	TB-PI	−56.29*	−54.96*	−55.41*	−59.33*
	TB-US	−48.55*	−47.12*	−47.67*	−48.76*
	PI-US	7.74	7.84	7.74	10.57

Note: Differences between groups are also presented. *Comparison between groups (ANOVA test) with $p < .05$.

do not test appropriately the influence of the defect anatomy (Keim et al., 2019; Ozkan Karaca & Tunar, 2021; Sahrmann et al., 2013; Sanz-Martin et al., 2021; Tuchscheerer et al., 2021). Other factors that have shown to influence biofilm removal include the macroscopic implant design or the thread configuration. A recently published in vitro study showed that a better cleaning effect occurred in implants with a reverse buttress and threads with wide interthread distance, compared to implants with a smaller thread pitch (Sanz-Martin et al., 2021).

The use of titanium brushes in this in vitro study demonstrated the highest relative cleaning activity resulting in residual ink surfaces between 9.14% and 18.07%. These results are better than those recently reported by an in vitro study (ranging between 39 and 48% (Sanz-Martin et al., 2021), although in this study only one type of defect configuration (circumferential) was used. It has been shown that this mechanical method can reduce the roughness of the implant surface (Cha et al., 2019) and its use has been recommended for decontamination during peri-implantitis surgery (Renvert & Polyzois, 2015). Different investigations have evaluated its efficacy as a decontamination method during surgical therapy. In preclinical studies, the use of titanium brushes in peri-implantitis experimental models has resulted in a higher degree of disease resolution (Carral et al., 2016) and greater marginal bone level gain, compared with the control group where the brush was not used (Vigano et al., 2019). Similarly, in clinical trials, the adjunctive use of titanium brushes for chemical treatment resulted in greater probing depth reductions (de Tapia, Valles, et al., 2019; Toma et al., 2019).

TABLE 3 Residual ink of the different groups (mean ± SD) expressed in percentage, analyzed from a 30° apical point of view in buccal, mesial, and distal sides on simulated defects types B, C, and E

		BUCCAL	MESIAL	DISTAL	LINGUAL
DEFECT "B"	AF	30.63 ± 9.08	36.69 ± 8.66	34.62 ± 10.44	
	TB	13.2 ± 5.99	17.42 ± 10.06	16.48 ± 16.58	
	PI	54.42 ± 6.08	57.84 ± 8.69	57.37 ± 8.57	
	US	36.85 ± 11.46	49.96 ± 9.87	42.47 ± 11.77	
	AF-TB	17.43*	19.28*	18.14*	
	AF-PI	−23.8*	−21.15*	−22.75*	
	AF-US	−6.22*	−13.27*	−7.85	
	TB-PI	−41.23*	−40.43*	−40.89*	
	TB-US	−23.66*	−32.54*	−25.99*	
	PI-US	17.57*	7.88	14.9	
DEFECT "C"	AF	31.48 ± 16.79	32.86 ± 18.43	27.63 ± 17.04	33.49 ± 13.25
	TB	12.66 ± 4.62	9.97 ± 5.23	10.98 ± 3.69	11.65 ± 3.47
	PI	50.6 ± 11.87	57.18 ± 8.39	57.4 ± 8.01	64.36 ± 9.72
	US	53.17 ± 15.14	68.65 ± 7.29	68.56 ± 6.17	77.02 ± 7.04
	AF-TB	18.81*	22.88*	16.65	21.84*
	AF-PI	−19.12*	−24.32*	−29.77*	−30.87*
	AF-US	−21.69*	−35.79*	−40.92*	−43.53*
	TB-PI	−37.93*	−47.2*	−46.42*	−52.71*
	TB-US	−40.51*	−58.68*	−57.57*	−65.37*
	PI-US	−2.58	−11.47	−11.15	−12.66
DEFECT "E"	AF	19.93 ± 7.8	22.72 ± 15.03	18.49 ± 9.74	23.13 ± 10.95
	TB	8.5 ± 3.1	10.26 ± 6.28	10.5 ± 5.26	11.13 ± 4.64
	PI	67.12 ± 6.05	65.52 ± 5.71	68.23 ± 7.33	68.52 ± 6.18
	US	63.41 ± 8.44	59.88 ± 10.28	66.32 ± 7.75	60.27 ± 10.33
	AF-TB	11.43	12.46	7.99	12
	AF-PI	−47.19*	−42.8*	−49.75*	−45.39*
	AF-US	−43.48*	−37.15*	−47.84*	−37.15*
	TB-PI	−58.62*	−55.26*	−57.73*	−57.39*
	TB-US	−54.91*	−49.61*	−55.82*	−49.14*
	PI-US	3.71	5.65	1.91	8.25

Note: Differences between groups are also presented. *Comparison between groups (ANOVA test) with $p < .05$.

Air-polishing devices have also shown a relative high cleaning effect on the implant surface, with percentages of residual ink ranging between 7.24% (±2.58) and 14.04% (±4.09), which is in agreement with two similar investigations reporting 5.0% (±1.40) and 16.10% (±3.70), respectively (Ozkan Karaca & Tunar, 2021). In this study, AF showed significantly better results than ultrasound tips, irrespective of the defect type. This advantage of air-polishing systems may be clinically relevant, since this mechanical decontamination method causes minimal affectation of the implant surface (Cha et al., 2019; Iatrou et al., 2021). However, this relatively high cleaning activity has not been homogenously reported in similar in vitro studies. While in some investigations (Keim et al., 2019) its use was associated with minimal amounts of residual ink (between 0.13% and 8.26%) (Tuchscheerer et al., 2021), others have reported amounts between 59.27% and 77.01% (Sanz-Martin et al., 2021. This heterogeneity can be explained by the different methods used in the different investigations, such as the type of ink or the evaluation method used to report the results.

Ultrasonic devices are probably the mechanical method most used by dental professionals in daily practice for implant surface debridement, both in the surgical and nonsurgical treatment of peri-implantitis. However, the results from the present investigation showed that irrespectively of the tip material (steel or peek), its relative cleaning effect was inferior to titanium brushes or air-polishing systems. Depending on the type of defect, the residual ink area after ultrasonic instrumentation ranged between 42.62% and 65.30%. These results are similar to those reported when used in circumferential intraosseous defects (between 24.97% and 48.05%) (Sanz-Martin et al., 2021), although other in vitro studies have

shown a higher cleaning activity (reporting between 15.9% and 21% of residual ink (Sahrmann et al., 2015), or between 11.4% and 19.69% (Keim et al., 2019)).

Furthermore, the macroscopic and microscopic effects of ultrasonic devices on the implant surface characteristics have been evaluated in different investigations, demonstrating that steel tips significantly damage the surface topography (Hakki et al., 2017; Sahrmann et al., 2021; Sanz-Martin et al., 2021). Although changes in the shape and material of the tip may reduce these side effects, still these ultrasonic tips cause more surface alterations, compared to air-polishing devices, especially in the thread area (Cha et al., 2019), which may favor bacterial recolonization (Louropoulou et al., 2012). Conversely, in clinical studies, the use of ultrasonic with a plastic tip demonstrated a greater therapeutic improvement than the air-polishing device with glycine powder in the treatment of mucositis (Blasi et al., 2016). This reveals that factors such as the access to hygiene allowed by the prosthetic restoration and supragingival plaque control by the patient can probably influence the subsequent behavior of the peri-implant tissues (de Tapia, Mozas, et al., 2019).

The results from the present study should be interpreted with caution, mainly due to the in vitro nature of this investigation using ink as an artificial biofilm, since the potential effect of the tested cleaning devices may be different when applied on implant surfaces contaminated with calculus and complex biofilms within the peri-implantitis lesions. However, the design of this investigation was aimed not only to assess the relative cleaning activity of these mechanical devices, but to assess how they could reach the affected surfaces depending on the defect morphology and area of application.

5 | CONCLUSIONS

Although none of the tested devices achieved complete elimination of the surrogate biofilm from standard implant surfaces, irrespective of the type of defect, titanium brushes, and air-polishing devices demonstrated a similar cleaning effect, being both significantly better than ultrasonic devices, irrespective of the tip material. All devices performed better when there was direct access to the affected surface and left more remnant ink when the surface was part of a narrow intraosseous defect and on the apical side of the threads.

AUTHOR CONTRIBUTIONS

Fernando Luengo: Conceptualization (lead); data curation (lead); formal analysis (equal); investigation (equal); methodology (equal); software (lead); writing – original draft (equal). **Fernando Noguerol:** Conceptualization (supporting); data curation (equal); investigation (equal); methodology (supporting). **Ignacio Sanz Martin:** Conceptualization (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Ignacio Sanz-Sánchez:** Supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Mariano Sanz:** Methodology (equal); project administration (lead); supervision (lead); validation (lead); visualization (equal); writing – original draft (equal); writing – review and editing (lead).

ACKNOWLEDGMENTS

The authors would like to thank the invaluable help of Dr. Ignacio Pedrinaci for his collaboration in the management of the 3D printing and other necessary material for this research and Mr. Alberto Iglesias Fábregas in the virtual design of the defects.

FUNDING INFORMATION

This study was self-funded by the ETEP Research Group, UCM, Madrid, Spain.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL

Ethics approval was not required for this in vitro study

ORCID

Fernando Luengo https://orcid.org/0000-0001-8106-6615
Javier Sanz-Esporrín https://orcid.org/0000-0003-0859-3149
Ignacio Sanz-Martín https://orcid.org/0000-0001-7037-1163
Ignacio Sanz-Sánchez https://orcid.org/0000-0002-3698-4772
Mariano Sanz https://orcid.org/0000-0002-6293-5755

REFERENCES

Blasi, A., Iorio-Siciliano, V., Pacenza, C., Pomingi, F., Matarasso, S., & Rasperini, G. (2016). Biofilm removal from implants supported restoration using different instruments: A 6-month comparative multicenter clinical study. *Clinical Oral Implants Research*, *27*(2), e68–e73. https://doi.org/10.1111/clr.12530

Carral, C., Munoz, F., Permuy, M., Linares, A., Dard, M., & Blanco, J. (2016). Mechanical and chemical implant decontamination in surgical peri-implantitis treatment: Preclinical "in vivo" study. *Journal of Clinical Periodontology*, *43*(8), 694–701. https://doi.org/10.1111/jcpe.12566

Cha, J. K., Paeng, K., Jung, U. W., Choi, S. H., Sanz, M., & Sanz-Martin, I. (2019). The effect of five mechanical instrumentation protocols on implant surface topography and roughness: A scanning electron microscope and confocal laser scanning microscope analysis. *Clinical Oral Implants Research*, *30*(6), 578–587. https://doi.org/10.1111/clr.13446

Chan, H. L., Lin, G. H., Suarez, F., MacEachern, M., & Wang, H. L. (2014). Surgical management of peri-implantitis: A systematic review and meta-analysis of treatment outcomes. *Journal of Periodontology*, *85*(8), 1027–1041. https://doi.org/10.1902/jop.2013.130563

Claffey, N., Clarke, E., Polyzois, I., & Renvert, S. (2008). Surgical treatment of peri-implantitis. *Journal of Clinical Periodontology*, *35*(Suppl 8), 316–332. https://doi.org/10.1111/j.1600-051X.2008.01277.x

Daubert, D. M., & Weinstein, B. F. (2019). Biofilm as a risk factor in implant treatment. *Periodontology 2000*, *81*(1), 29–40. https://doi.org/10.1111/prd.12280

de Tapia, B., Mozas, C., Valles, C., Nart, J., Sanz, M., & Herrera, D. (2019). Adjunctive effect of modifying the implant-supported prosthesis in the treatment of peri-implant mucositis. *Journal of Clinical Periodontology*, *46*(10), 1050–1060. https://doi.org/10.1111/jcpe.13169

de Tapia, B., Valles, C., Ribeiro-Amaral, T., Mor, C., Herrera, D., Sanz, M., & Nart, J. (2019). The adjunctive effect of a titanium brush in implant surface decontamination at peri-implantitis surgical regenerative interventions: A randomized controlled clinical trial. *Journal of Clinical Periodontology*, *46*(5), 586–596. https://doi.org/10.1111/jcpe.13095

de Waal, Y. C., Raghoebar, G. M., Meijer, H. J., Winkel, E. G., & van Winkelhoff, A. J. (2016). Prognostic indicators for surgical peri-implantitis treatment. *Clinical Oral Implants Research*, *27*(12), 1485–1491. https://doi.org/10.1111/clr.12584

Derks, J., & Tomasi, C. (2015). Peri-implant health and disease. A systematic review of current epidemiology. *Journal of Clinical Periodontology*, *42*(Suppl 16), S158–S171. https://doi.org/10.1111/jcpe.12334

Estefania-Fresco, R., Garcia-de-la-Fuente, A. M., Egana-Fernandez-Valderrama, A., Bravo, M., & Aguirre-Zorzano, L. A. (2019). One-year results of a nonsurgical treatment protocol for peri-implantitis. A retrospective case series. *Clinical Oral Implants Research*, *30*(7), 702–712. https://doi.org/10.1111/clr.13456

Figuero, E., Graziani, F., Sanz, I., Herrera, D., & Sanz, M. (2014). Management of peri-implant mucositis and peri-implantitis. *Periodontology 2000*, *66*(1), 255–273. https://doi.org/10.1111/prd.12049

Hakki, S. S., Tatar, G., Dundar, N., & Demiralp, B. (2017). The effect of different cleaning methods on the surface and temperature of failed titanium implants: An in vitro study. *Lasers in Medical Science*, *32*(3), 563–571. https://doi.org/10.1007/s10103-017-2149-2

Heitz-Mayfield, L. J. (2008). Peri-implant diseases: Diagnosis and risk indicators. *Journal of Clinical Periodontology*, *35*(Suppl 8), 292–304. https://doi.org/10.1111/j.1600-051X.2008.01275.x

Heitz-Mayfield, L. J., & Mombelli, A. (2014). The therapy of peri-implantitis: A systematic review. *The International Journal of Oral & Maxillofacial Implants*, *29*, 325–345. https://doi.org/10.11607/jomi.2014suppl.g5.3

Iatrou, P., Chamilos, C., Nickles, K., Ratka, C., Eickholz, P., & Petsos, H. (2021). In vitro efficacy of three different nonsurgical implant surface decontamination methods in three different defect configurations. *The International Journal of Oral & Maxillofacial Implants*, *36*(2), 271–280. https://doi.org/10.11607/jomi.8864

Jung, R. E., Zembic, A., Pjetursson, B. E., Zwahlen, M., & Thoma, D. S. (2012). Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clinical Oral Implants Research*, *23*(Suppl 6), 2–21. https://doi.org/10.1111/j.1600-0501.2012.02547.x

Keim, D., Nickles, K., Dannewitz, B., Ratka, C., Eickholz, P., & Petsos, H. (2019). In vitro efficacy of three different implant surface decontamination methods in three different defect configurations. *Clinical Oral Implants Research*, *30*(6), 550–558. https://doi.org/10.1111/clr.13441

Krithikadatta, J., Gopikrishna, V., & Datta, M. (2014). CRIS guidelines (checklist for reporting in-vitro studies): A concept note on the need for standardized guidelines for improving quality and transparency in reporting in-vitro studies in experimental dental research. *Journal of Conservative Dentistry*, *17*(4), 301–304. https://doi.org/10.4103/0972-0707.136338

Linares, A., Pico, A., Blanco, C., & Blanco, J. (2019). Adjunctive systemic metronidazole to nonsurgical therapy of peri-implantitis with Intrabony defects: A retrospective case series study. *The International Journal of Oral & Maxillofacial Implants*, *34*(5), 1237–1245. https://doi.org/10.11607/jomi.7343

Louropoulou, A., Slot, D. E., & Van der Weijden, F. A. (2012). Titanium surface alterations following the use of different mechanical instruments: A systematic review. *Clinical Oral Implants Research*, *23*(6), 643–658. https://doi.org/10.1111/j.1600-0501.2011.02208.x

Meyle, J. (2012). Mechanical, chemical and laser treatments of the implant surface in the presence of marginal bone loss around implants. *European Journal of Oral Implantology*, *5*, S71–S81.

Mombelli, A., & Lang, N. P. (1994). Microbial aspects of implant dentistry. *Periodontol 2000*, *4*, 74–80. https://doi.org/10.1111/j.1600-0757.1994.tb00007.x

Nart, J., Pons, R., Valles, C., Esmatges, A., Sanz-Martin, I., & Monje, A. (2020). Non-surgical therapeutic outcomes of peri-implantitis: 12-month results. *Clinical Oral Investigations*, *24*(2), 675–682. https://doi.org/10.1007/s00784-019-02943-8

Ozkan Karaca, E., & Tunar, O. L. (2021). In vitro evaluation of surface cleaning methods in two different implant defect angulations: A pilot study. *Biotechnology & Biotechnological Equipment*, *35*(1), 560–566. https://doi.org/10.1080/13102818.2021.1905063

Papaspyridakos, P., Barizan Bordin, T., Kim, Y. J., DeFuria, C., Pagni, S. E., Chochlidakis, K., Rolim Teixeira, E., & Weber, H. P. (2018). Implant survival rates and biologic complications with implant-supported fixed complete dental prostheses: A retrospective study with up to 12-year follow-up. *Clinical Oral Implants Research*, *29*(8), 881–893. https://doi.org/10.1111/clr.13340

Pjetursson, B. E., Thoma, D., Jung, R., Zwahlen, M., & Zembic, A. (2012). A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. *Clinical Oral Implants Research*, *23*(Suppl 6), 22–38. https://doi.org/10.1111/j.1600-0501.2012.02546.x

Ramanauskaite, A., Daugela, P., & Juodzbalys, G. (2016). Treatment of peri-implantitis: Meta-analysis of findings in a systematic literature review and novel protocol proposal. *Quintessence International*, *47*(5), 379–393. https://doi.org/10.3290/j.qi.a35131

Renvert, S., Lindahl, C., & Persson, G. R. (2018). Occurrence of cases with peri-implant mucositis or peri-implantitis in a 21-26 years follow-up study. *Journal of Clinical Periodontology*, *45*(2), 233–240. https://doi.org/10.1111/jcpe.12822

Renvert, S., Persson, G. R., Pirih, F. Q., & Camargo, P. M. (2018). Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. *Journal of Periodontology*, *89*(Suppl 1), S304–S312. https://doi.org/10.1002/JPER.17-0588

Renvert, S., Polyzois, I., & Claffey, N. (2012). Surgical therapy for the control of peri-implantitis. *Clinical Oral Implants Research*, *23*(Suppl 6), 84–94. https://doi.org/10.1111/j.1600-0501.2012.02554.x

Renvert, S., & Polyzois, I. N. (2015). Clinical approaches to treat peri-implant mucositis and peri-implantitis. *Periodontology 2000*, *68*(1), 369–404. https://doi.org/10.1111/prd.12069

Renvert, S., Roos-Jansaker, A. M., & Claffey, N. (2008). Non-surgical treatment of peri-implant mucositis and peri-implantitis: A literature review. *Journal of Clinical Periodontology*, *35*(Suppl 8), 305–315. https://doi.org/10.1111/j.1600-051X.2008.01276.x

Romandini, M., Lima, C., Pedrinaci, I., Araoz, A., Soldini, M. C., & Sanz, M. (2021). Prevalence and risk/protective indicators of peri-implant diseases: A university-representative cross-sectional study. *Clinical Oral Implants Research*, *32*(1), 112–122. https://doi.org/10.1111/clr.13684

Ruhling, A., Schlemme, H., Konig, J., Kocher, T., Schwahn, C., & Plagmann, H. C. (2002). Learning root debridement with curettes and power-driven instruments. Part I: A training program to increase effectivity. *Journal of Clinical Periodontology*, *29*(7), 622–629. https://doi.org/10.1034/j.1600-051x.2002.290706.x

Sahrmann, P., Ronay, V., Hofer, D., Attin, T., Jung, R. E., & Schmidlin, P. R. (2015). In vitro cleaning potential of three different implant

debridement methods. *Clinical Oral Implants Research*, *26*(3), 314–319. https://doi.org/10.1111/clr.12322

Sahrmann, P., Ronay, V., Sener, B., Jung, R. E., Attin, T., & Schmidlin, P. R. (2013). Cleaning potential of glycine air-flow application in an in vitro peri-implantitis model. *Clinical Oral Implants Research*, *24*(6), 666–670. https://doi.org/10.1111/j.1600-0501.2012.02445.x

Sahrmann, P., Winkler, S., Gubler, A., & Attin, T. (2021). Assessment of implant surface and instrument insert changes due to instrumentation with different tips for ultrasonic-driven debridement. *BMC Oral Health*, *21*(1), 25. https://doi.org/10.1186/s12903-020-01384-0

Sanz-Martin, I., Paeng, K., Park, H., Cha, J. K., Jung, U. W., & Sanz, M. (2021). Significance of implant design on the efficacy of different peri-implantitis decontamination protocols. *Clinical Oral Investigations*, *25*(6), 3589–3597. https://doi.org/10.1007/s00784-020-03681-y

Schou, S., Holmstrup, P., Hjorting-Hansen, E., & Lang, N. P. (1992). Plaque-induced marginal tissue reactions of osseointegrated oral implants: A review of the literature. *Clinical Oral Implants Research*, *3*(4), 149–161. https://doi.org/10.1034/j.1600-0501.1992.030401.x

Schwarz, F., Derks, J., Monje, A., & Wang, H. L. (2018). Peri-implantitis. *Journal of Periodontology*, *89*(Suppl 1), S267–S290. https://doi.org/10.1002/JPER.16-0350

Schwarz, F., Herten, M., Sager, M., Bieling, K., Sculean, A., & Becker, J. (2007). Comparison of naturally occurring and ligature-induced peri-implantitis bone defects in humans and dogs. *Clinical Oral Implants Research*, *18*(2), 161–170. https://doi.org/10.1111/j.1600-0501.2006.01320.x

Serino, G., & Hultin, K. (2019). Periimplant disease and prosthetic risk indicators: A literature review. *Implant Dentistry*, *28*(2), 125–137. https://doi.org/10.1097/ID.0000000000000841

Steiger-Ronay, V., Merlini, A., Wiedemeier, D. B., Schmidlin, P. R., Attin, T., & Sahrmann, P. (2017). Location of unaccessible implant surface areas during debridement in simulated peri-implantitis therapy. *BMC Oral Health*, *17*(1), 137. https://doi.org/10.1186/s12903-017-0428-8

Subramani, K., & Wismeijer, D. (2012). Decontamination of titanium implant surface and re-osseointegration to treat peri-implantitis: A literature review. *The International Journal of Oral & Maxillofacial Implants*, *27*(5), 1043–1054.

Toma, S., Brecx, M. C., & Lasserre, J. F. (2019). Clinical evaluation of three surgical modalities in the treatment of peri-Implantitis: A randomized controlled clinical trial. *Journal of Clinical Medicine*, *8*(7), 1–12. https://doi.org/10.3390/jcm8070966

Tuchscheerer, V., Eickholz, P., Dannewitz, B., Ratka, C., Zuhr, O., & Petsos, H. (2021). In vitro surgical and non-surgical air-polishing efficacy for implant surface decontamination in three different defect configurations. *Clinical Oral Investigations*, *25*(4), 1743–1754. https://doi.org/10.1007/s00784-020-03476-1

Vigano, P., Apaza Alccayhuaman, K. A., Sakuma, S., Amari, Y., Bengazi, F., & Botticelli, D. (2019). Use of TiBrush for surface decontamination at peri-implantitis sites in dogs: Radiographic and histological outcomes. *Journal of Investigative and Clinical Dentistry*, *10*(1), e12378. https://doi.org/10.1111/jicd.12378

How to cite this article: Luengo, F., Sanz-Esporrín, J., Noguerol, F., Sanz-Martín, I., Sanz-Sánchez, I., & Sanz, M. (2022). In vitro effect of different implant decontamination methods in three intraosseous defect configurations. *Clinical Oral Implants Research*, *33*, 1087–1097. https://doi.org/10.1111/clr.13991