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Removal of simulated biofilm at different implant crown designs with interproximal oral hygiene aids: An *in vitro* study

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Abstract

Objectives: To compare the removal of simulated biofilm at two different implant-supported restoration designs with various interproximal oral hygiene aids.

Methods: Mandibular models with a missing first molar were fabricated and provided with single implant analogues (centrally or distally placed) and two different crown designs (conventional [CCD] and alternative crown design [ACD]). Occlusion spray was applied to the crowns to simulate artificial biofilm. Thirty participants (dentists, dental hygienists, and laypersons) were equally divided and asked to clean the interproximal areas with five different cleaning devices to further evaluate if there were differences in their cleaning ability. The outcome was measured via standardized photos and the cleaning ratio, representing the cleaned surfaces in relation to the respective crown surface. Statistical analysis was performed by linear mixed-effects model with fixed effects for cleaning tools, surfaces, crown design and type of participant, and random effects for crowns.

Results: The mean cleaning ratio for the investigated tools and crown designs were (in%): Super floss: 76 ± 13/ACD and 57 ± 14/CCD (highest cleaning efficiency), followed by dental floss: 66 ± 13/ACD and 56 ± 15/CCD, interdental brush: 55 ± 10/ACD and 45 ± 9/CCD, electric interspace brush: 31 ± 10/ACD and 30 ± 1/CCD, microdroplet floss: 8 ± 9/ACD and 9 ± 8/CCD. There was evidence of an overall effect of each factor "cleaning tool," "surface," "crown design," and "participant" ($p < 0.0001$).

Conclusions: ACD allowed more removal of the artificial biofilm than CCD with Super floss, dental floss, and interdental brush. Flossing and interproximal brushing were the most effective cleaning methods. A complete removal of the artificial biofilm could not be achieved in any group.

KEYWORDS
health behavior, prosthodontics, soft tissue-implant interactions

1 | INTRODUCTION

One of the major challenges in implant dentistry is prevention and treatment of peri-implant diseases, which are classified into mucositis and peri-implantitis (Albrektsson & Isidor, 1994; Zitzmann & Berglundh, 2008). Recent reviews and meta-analyses reported a mean prevalence of 43%–47% for patient-based mucositis and 20%–22% for peri-implantitis, 5–10 years after implant placement (Derks & Tomasi, 2015; Lee, Huang, Zhu, & Weltman, 2017). The high incidence of bacterial accumulation on implant surfaces (biofilm) is considered one of the main causes of peri-implant diseases (Pontoriero et al., 1994; Renvert & Polyzois, 2015; Zitzmann, Berglundh, Marinello, & Lindhe, 2001). Several treatment protocols have been identified in the literature and most focused on removal of the contaminating agents from the implant surfaces. However, due to the missing reliable evidence for any of the various proposed treatment protocols, the therapy outcome of peri-implantitis remains unpredictable (Lindhe & Meyle, 2008; Schwarz, Schmucker, & Becker, 2015). Therefore, prevention and maintenance of healthy tissues around implants appear to be even more important. According to up to date knowledge, long-term success of dental implants is mainly based on proper case selection, proper treatment planning, implant placement, and properly designed restorations. Moreover, and in particular, regular monitoring of the implants and accurate maintenance by both patients and dental care professionals is considered a prerequisite for prevention of peri-implant diseases (Gulati, Govila, Anand, & Anand, 2014; Wolfart, 2016).

Due to the anatomical differences between teeth and dental implants, factors that are known to have an impact on periodontal health differ from those influencing peri-implant health. In addition to difficult cleaning accessibility seen around natural teeth in interproximal areas, other factors such as implant position, diameter, and restoration design are considered important factors for oral hygiene considerations around dental implants. Especially, size discrepancies between the restoration and the implant may promote the creation of niches and thereby leading to restricted accessibility for sufficient interproximal oral hygiene and pre-disposition of peri-implant diseases (O'Mahony, MacNeill, & Cobb, 2000; Serino & Strom, 2009). Previous studies concluded that restoration designs as well as effective application of dental devices in oral home care are considered as part of the precautionary measures for periodontal/peri-implant health (Chongcharoen, Lulic, & Lang, 2012; Sharma, Klukowska, Mielczarek, Grender, & Qaqish, 2012).

Therefore, the development of an alternative crown design in combination with a modified implant position may be helpful to avoid the creation of the above mentioned niches with restricted cleaning accessibility in cases where the usual central implant position obligates the placement of a restoration with a much wider width than the implant diameter and therefore hampering adequate interproximal hygiene. Here, the implant can be placed in an eccentric position putting into consideration the minimum distance of 1.5 mm between the implant shoulder and the neighboring teeth. With such implant position, a new designed slim restoration consisting of a "premolar crown" combined with a cantilevered pontic can be fabricated (Wolfart, 2016). With this design, oral hygiene devices can be guided through the interproximal channels, which may be helpful in achieving a better oral hygiene around the implant-supported restorations.

In addition to restoration design, personal home care and consistent professional maintenance have proven to be critical for the long-term outcome of dental implants (Serino & Strom, 2009; Silverstein & Kurtzman, 2006). It has been reported that a normal toothbrush alone is not enough to clean interproximal areas (Berchier, Slot, Haps, & Van der Weijden, 2008; Sjogren, Lundberg, Birkhed, Dudgeon, & Johnson, 2004). Interproximal brushes have shown to remove interproximal plaque of dental implants (Chongcharoen et al., 2012), as they are able to penetrate into the peri-implant sulcus. There is also evidence, that additional use of dental floss reduces gingivitis and periodontitis (Sambunjak et al., 2011), but evidence is scarce about their beneficial effect on reducing the risk of peri-implantitis. Nowadays, numerous interdental cleaning devices are available on the market. However, to the knowledge of the authors, there is a lack of research regarding interproximal cleaning around implant restorations, and which of the available interdental cleaning devices is the most appropriate in terms of interdental cleaning efficiency (Louropoulou, Slot, & Van der Weijden, 2014).

As crown design, personal home care and consistent professional maintenance seem to be important for the long-term outcome of implant restorations, and with the plethora of cleaning devices available nowadays, the main aim of this *in vitro* study was to evaluate the feasibility of interproximal removal of artificial biofilm at two different implant crown designs, with five commercially available interdental cleaning devices among three different participant groups, such as dentists, dental hygienists, and laypersons. The null-hypothesis was that crown design, cleaning tools, and participant group have no impact on the cleaning efficacy around implant-supported restorations.

2 | MATERIAL AND METHODS

Thirty subjects participated in this study (10 dentists/10 dental hygienists/10 lay persons). Two mandibular models with a missing lower first molar were fabricated from transparent cold-cured polymer (PalaPress, Heraeus Kulzer GmbH & Co KG) as copies from Frasaco models (Frasaco) and equipped with individual gingival masks (Gingifast rigid, Zhermack) in the edentulous region of tooth 36. Implant laboratory analogues (CAMLOG Biotechnologies AG) with an implant–abutment diameter of 4.3 mm were placed 3 mm beneath the suppositional cemento-enamel junction in two sagittal positions. They were placed either centrally within the tooth gap (in the prosthetic axis of a molar crown) (Figure 1a) or distally (in the prosthetic axis of the distal root of a first lower molar) (Figure 1b).

For the restorations, titanium abutments (Titanium base CAD/CAM, CAMLOG Biotechnologies AG) combined with monolithic lithium disilicate crowns (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) were used. The crown designs comprised "conventional crown design = CCD" (central implant insertion, molar-shaped crown; Figure 1e), and "alternative crown design = ACD" (distal implant insertion, distal premolar crown, mesial pontic; Figure 1f). In the latter, the pontic´s lower cross-section was root-shaped and therefore created an additional "interradicular" access path (underneath the crown-pontic connector) for oral hygiene measures. This guided oral hygiene devices through three interproximal channels: mesial/distal alongside the implant, "interradicular" alongside the implant and mesial/distal of the entire restoration.

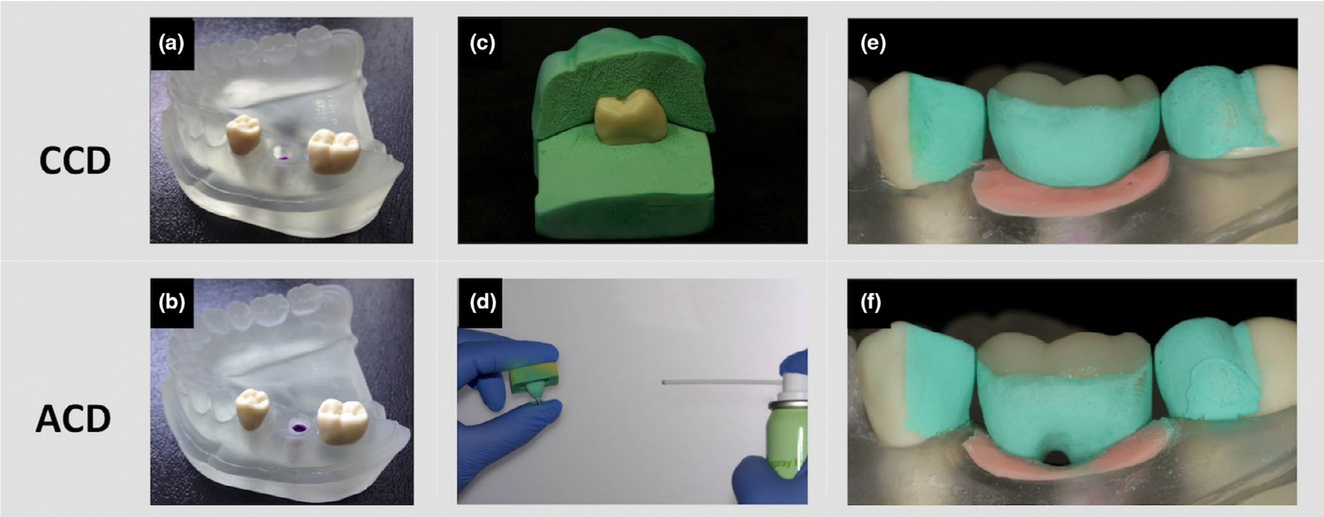

FIGURE 1 (a) Model with centrally placed implant analogue in regio 36 for CCD. (b) Model with distally placed implant analogue in regio 36 for ACD. (c and d) Standardized application of green occlusion spray. (e) CCD and (f) ACD crowns and neighboring surfaces with artificial biofilm (green color) before cleaning

The mandibular model was fixed in a phantom head (KaVo dental patient simulator, KaVo Dental GmbH) in an upright position and participants were positioned in front of the phantom head simulating oral hygiene care given by a healthcare provider. The crowns and the corresponding mesial and distal neighboring surfaces were provided with green occlusion spray (Occlu-Spray, Hager & Werken) in a standardized manner to simulate a biofilm on the restoration surfaces. For this, the crowns and neighboring teeth were first taken outside the mandibular model. Then, silicone keys from pliable silicone (Orbis Silikon, ORBIS Dental) were manufactured to (a) being able to hold the respective crowns and teeth and (b) to provide the respective surfaces with a thin layer of occlusion spray by spraying from a distance of 2–5 cm with a one-time back and forth movement (Figure 1c,d).

Verbal instructions as well as practical demonstrations were given to each participant before starting the interproximal cleaning

TABLE 1 Different cleaning tools used in the study and instructions for use demonstrated to participants

Cleaning tool	Acronym	Name and manufacturer	Instructions for use
Electric Water Flosser	AF	Sonicare Airfloss, Philips, Germany	• AF tip placed buccally with gentle pressure in the cleaning area mesial and distal to the implant ("interproximal channels"). • One spray burst for each cleaning area only.
Electric Interspace Brush	OB	Oral B Interspace, Procter & Gamble, Germany	• Interspace brush in function placed horizontally and from buccal side in cleaning areas mesial and distal to the implant ("interproximal channels"). • Repeated only once for each area.
Interdental Brush (Size 1.4 mm)	ID	Gum, Proxabrush cylindrical, Sunstar, USA	• ID brush angled to 45° and placed horizontally and from buccal side in the cleaning areas ("interproximal channels"). • Back and forth vibrating movements (five times).
Dental Floss (non-waxed)	DF	Oral B, Procter & Gamble, Germany	• Floss of 45 cm length threaded gently in a back and forth movement from buccal to oral into the interproximal areas mesial and distal to the implant. • Flossing up and down, five times for each area. • With ACD, floss was moved additionally under the root-shaped pontic.
Super Floss	SF	Oral B, Procter & Gamble, Germany	• Stiff segment of the Superfloss threaded into the interproximal areas mesial and distal to the implant and then pulled until the fuzzy segment is reached. • Flossing up and down, five times for each area. • With ACD, floss was moved additionally under the root-shaped pontic.

Abbreviations: AF: electric water flosser; DF: dental floss; ID: interdental brush; OB: electric interspace brush; SF: Super Floss.

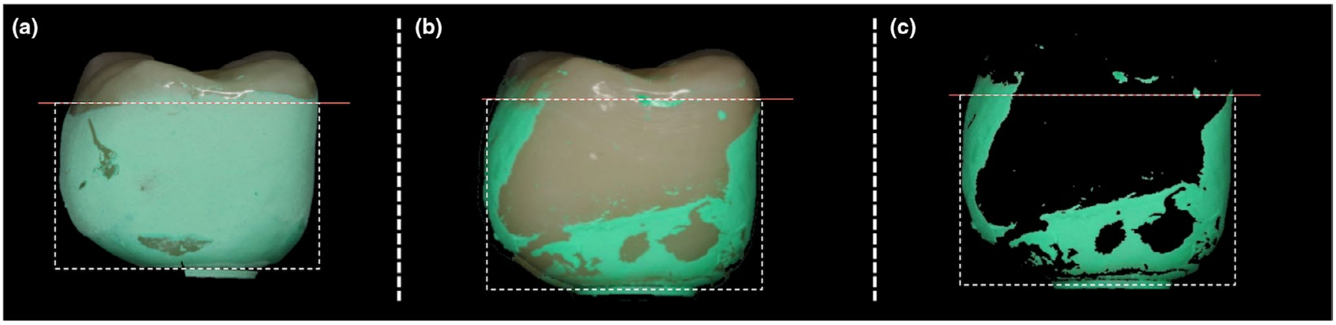

FIGURE 2 (a) Image of a non-cleaned surface from the distal aspect of a CCD crown. (b and c) After cleaning: Image processing and estimation of cleaning ratio by segmentation of color threshold values was performed. The framed area is the region of interest (ROI), which was covered with green occlusal spray prior to the cleaning process and has then been considered for assessing the cleaned surface in relation to the whole green surface within this framed area

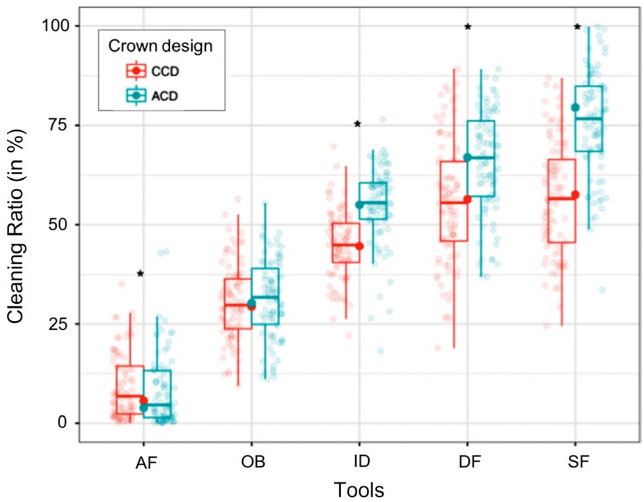

FIGURE 3 Cleaning ratio by cleaning tools (AF, OB, ID, DF, SF) and crown design (CCD, ACD) for combined surfaces. The stars indicate where significant differences could be shown between the crown designs ($p < 0.05$). Solid colored dots represent estimates from the fitted model

procedure with the different tools. The investigated cleaning tools as well as the instructions for use demonstrated to the participants are shown in Table 1.

The order of the applied cleaning tools and the starting crown design was determined by a randomization program (Excel, Microsoft Corporation). The number of crown designs was equal for all participant groups, thus each participant cleaned the same number of crowns. Every tool was used once per participant. After every individual cleaning attempt, the crowns, neighboring teeth, and cleaning devices were exchanged.

After each test, crowns were carefully removed from the models and standardized photos from four different perpendicular directions were taken (Canon EOS 5D, Mark II, Canon). The four surfaces that were photographed were the mesial, the distal, the buccal, and the basal part, by which is meant the bottom side of the crown. The outcome was measured via the cleaning ratio (in %), which represents the sum of the cleaned pixels in relation to the total sum of pixels belonging to the whole respective crown surface. For this, image processing and estimation of cleaning ratio by segmentation of color threshold values (color thresholding) was performed.

In order to numerically assess the cleaned surfaces, a ratio of the cleaned area to the region of interest (ROI) was estimated. ROI interprets the area of the crown, which is covered with green occlusal spray prior to the cleaning experiment (framed area in Figure 2a). In order to provide a valid comparison, ROI was unified for all crowns, but specifically for every surface. For that reason, regions with no occlusal spray were excluded prior to the experiment. To do that, for all corresponding crowns, an upper ROI border had to be derived based on the edge between green and non-marked area. For this, in every photo of distal and mesial surfaces borderlines were drawn through the lowest point of the detected edges. Then, a common line for all corresponding crown surfaces was derived using "truncated mean computed" over all individual lines. After that, the ROI could be segmented from the top using the derived line (orange line in Figure 2). In the segmented ROI, the area marked with green was calculated as a sum of pixels lying above the color threshold. All other pixels were labeled as the cleaned area (framed area in Figure 2b,c). The quality indicator was computed as a ratio of the sum of the cleaned pixels to the total sum of pixels belonging to the ROI (Figure 2). All numerical values were acquired with a custom image processing software implemented in C++ using Open CV library.

For statistical analysis, only data on distal (D; N = 297 photos), mesial (M; N = 295 photos), and basal (B; N = 300 photos) surfaces were included (in total N = 892). Altogether eight photos could not be used for analysis and statistics because borderlines could not be clearly drawn. The statistical analysis was performed using linear mixed-effects model with fixed effects for cleaning tools, surfaces, crown design and type of participants, and random effects for crowns. Two-way interactions of fixed effects were included in the model. The outcome variable was logit transformed in the analysis. The R Program for Statistical Computing (R Foundation for Statistical Computing, Vienna, Austria. URL hLps://www.R-project.org/.) (R version 3.2.5) was used.

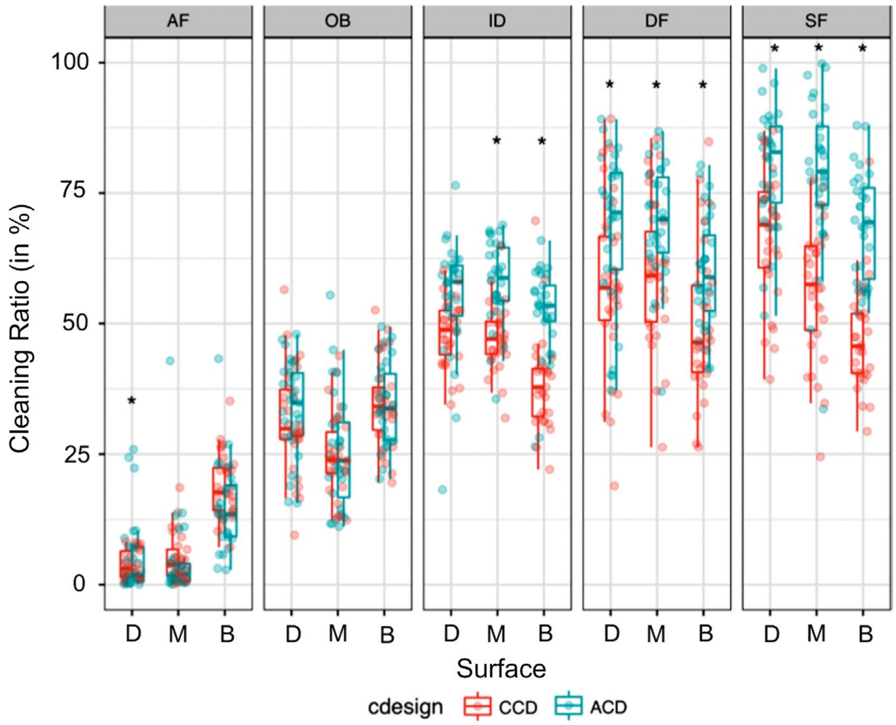

FIGURE 4 Cleaning ratio by cleaning tools (AF, OB, ID, DF, SF), surfaces (M = mesial, D = distal, B = basal), and crown design (CCD, ACD). The stars indicate where significant differences could be shown between the crown designs ($p < 0.05$)

TABLE 2 Cleaning ratio (Mean ± *SD*, in %) by tool, surface (mesial, distal, basal), and crown design (CCD, ACD).

	Mesial			Distal			Basal		
	CCD	*p* value	ACD	CCD	*p* value	ACD	CCD	*p* value	ACD
AF	5 ± 5	≈0.25	5 ± 8	4 ± 3	<0.02	5 ± 7	19 ± 6	≈0.06	15 ± 8
OB	25 ± 8	≈0.97	26 ± 11	32 ± 10	≈1.00	34 ± 9	35 ± 8	≈1.00	35 ± 8
ID	47 ± 64	<0.00	58 ± 8	48 ± 62	≈0.06	55 ± 11	39 ± 9	<0.02	52 ± 9
DF	59 ± 14	<0.00	70 ± 11	58 ± 16	<0.03	68 ± 15	50 ± 15	<0.01	60 ± 11
SF	56 ± 13	<0.00	79 ± 15	67 ± 12	<0.00	80 ± 11	47 ± 10	<0.00	69 ± 10

Note: *p* values are given for the comparison between the different crown designs in dependence of the measured surfaces. The symbol "≈" means no significant difference, while "<" or ">" indicate significant differences.
Abbreviations: ACD: alternative crown design; AF: electric water flosser; CCD: conventional crown design; DF: dental floss; ID: interdental brush; OB: electric interspace brush; SF: Super Floss.

3 | RESULTS

The outcome of the participants' cleaning attempts of the crown surfaces was measured via the cleaning ratio (in %), which represents the cleaned surface in relation to the whole respective crown surface after cleaning process with each cleaning device. For example, a cleaning ratio of 76% means that nearly ¾ of the respective crown surface was free of occlusion spray. The mean cleaning ratio for each of the investigated tools and crown designs for combined surfaces (mesial, distal and basal) was as follows (in%; ±*SD*): Super floss (SF): 76 ± 13/ACD and 57 ± 14/CCD with the highest cleaning efficiency, followed by dental floss (DF): 66 ± 13/ACD and 56 ± 15/CCD, interdental brush (ID): 55 ± 10/ACD and 45 ± 9/CCD, electric interspace brush (OB): 31 ± 10/ACD and 30 ± 10/CCD, and microdroplet floss (AF): 8 ± 9/ACD and 9 ± 8/CCD (Figure 3).

Figure 4 illustrates the mean cleaning ratio for each of the investigated tools and crown designs in dependence of the investigated single surfaces (mesial, distal, and basal). The related data are shown in Table 2.

Figure 5 illustrates the mean cleaning ratio for each of the investigated tools and crown designs in dependence of the participant types (dentist [DT], dental hygienist [DH] and layperson [LP]). The related data are shown in Table 3.

Overall tests for the factors "Cleaning tools," "Surface", "Crown design," and "Participant type" showed that there is evidence of an overall effect of each of the factors (all $p < 0.0001$). For the main effect of the crown design without considering the other factors, a significant difference in favor of the ACD ($p = 0.002$) could be shown. For the efficacy of the single cleaning tools without distinguishing the crown designs, significant differences could be shown

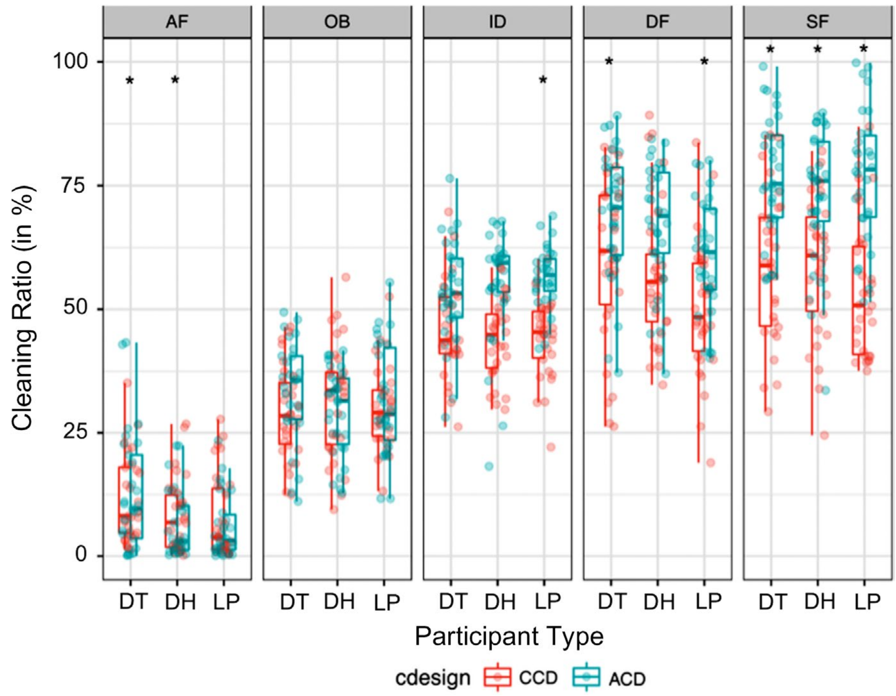

FIGURE 5 Cleaning ratio by cleaning tools (AF, OB, ID, DF, SF), participant types (dentist [DT], dental hygienist [DH], and layperson [LP]) and crown design (CCD, ACD). The stars indicate where significant differences could be shown between the crown designs

TABLE 3 Cleaning ratio (Mean ± *SD*, in %) by tool, participant type (dentist [DT], dental hygienist [DH] and layperson [LP]) and crown design (CCD, ACD).

	DT			DH			LP		
	CCD	*p* value	ACD	CCD	*p* value	ACD	CCD	*p* value	ACD
AF	12 ± 9	<0.022	13 ± 12	8 ± 7	>0.001	6 ± 7	8 ± 9	≈0.089	6 ± 6
OB	29 ± 10	≈1.000	34 ± 10	32 ± 12	≈0.976	29 ± 9	30 ± 8	≈0.999	32 ± 11
ID	46 ± 10	≈0.058	53 ± 10	44 ± 8	≈0.391	55 ± 12	44 ± 8	<0.012	57 ± 6
DF	60 ± 17	<0.031	69 ± 13	57 ± 14	≈0.268	67 ± 12	50 ± 14	<0.006	61 ± 12
SF	58 ± 15	<0.000	77 ± 12	59 ± 14	<0.000	73 ± 14	54 ± 13	<0.000	77 ± 13

Note: *p* values are given for the comparison between the different crown designs in dependence of the participant groups. The symbol "≈" means no significant difference, while "<" or ">" indicate significant differences.
Abbreviations: ACD: alternative crown design; AF: electric water flosser; CCD: conventional crown design; DF: dental floss; ID: interdental brush; OB: electric interspace brush; SF: Super Floss.

between the tools (Figure 6). For the participant groups, the cleaning efficacy was better with dentists in comparison with dental hygienists ($p < 0.019$) and to lay persons ($p < 0.001$). Dental hygienists showed higher cleaning efficacy in comparison with the laypersons ($p = 0.027$).

Figure 7 provides a qualitative visual assessment of the cleaning ratio of the two crown designs at their basal surfaces (bottom).

4 | DISCUSSION

This *in vitro* study was designed to evaluate the interproximal cleaning efficacy of different cleaning devices around two differently designed implant-supported crown restorations among three different participant groups. The results indicate that the ACD with a distally placed implant might promote superior cleaning efficacy compared to the CCD. Furthermore, results of this *in vitro* showed that SF, DF, and ID were the most effective among all the investigated cleaning tools. In addition, laypersons were significantly less effective in removing the artificial biofilm in the interproximal regions compared to hygienists and dentists. Therefore, all null hypotheses set in this study could be rejected.

The higher cleaning efficacy at the ACD in the current study may be explained by the better accessibility achieved by the presence of a fine tunnel between the implant and pontic. The eccentrically placed implant results in a restoration, which is more compatible with the implant diameter and therefore prevents the creation of niches and facilitates accessibility. Furthermore, restorations where

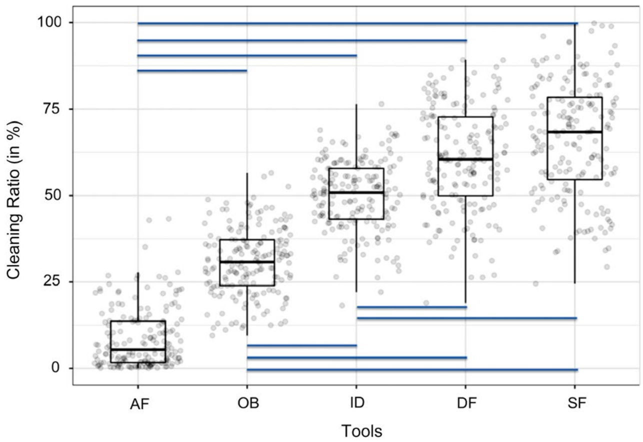

FIGURE 6 Pairwise comparison of the main effect of tools regardless of the crown designs, surfaces and participant groups. The blue lines indicate where significant differences could be shown between the tools. Except for the tools SF and DF, there were significant differences between all the tools

even probing of pockets is very difficult due to the unfavorable relation between superstructure and implant diameter can be avoided. As a consequence, biological complications may be reduced or prevented, which may have a positive effect on the long-term outcome of implants (Serino & Strom, 2009).

Assuming that this crown design shows more advantageous properties from a biological point of view, technical complications should also be addressed before considering this crown design as a safe and reliable treatment option. In this context, it has been reported that technical complications are much more frequent in implant restorations than biological ones (Pjetursson, Asgeirsson, Zwahlen, & Sailer, 2014; Sailer, Muhlemann, Zwahlen, Hammerle, & Schneider, 2012). Especially in implant-supported prostheses with cantilever extensions, the risk of functional overloading of the implant and the prosthetic restoration near the cantilever extension are considered to be critical (Romeo & Storelli, 2012). However, the impact of cantilevers on the long-term behavior and technical complications of cantilevered short-span or even single implant-supported restorations, such as ACDs, remains unknown, due to dearth of scientific evidence (Aglietta et al., 2009; Torrecillas-Martinez et al., 2014). According to most recent reviews, studies dealing with this topic are few, heterogeneously designed, non-randomized and partially non-controlled and do not include or report all confounding factors that may influence the stability of implants and restorations with cantilevers (number, length and diameter of implants, implant connection, length, height, and position of the cantilever, occlusion, opposing dentition, etc.); making it difficult to draw clear conclusions (Aglietta et al., 2009; Romeo & Storelli, 2012; Torrecillas-Martinez et al., 2014).

In regard to the interproximal cleaning tools, significantly higher cleaning efficacy was seen with flosses (SF, DF) and interdental brushes (ID) for both crown designs. To the knowledge of the authors, studies investigating the cleaning efficacy of tools for interproximal areas around implant restorations are rare (Louropoulou et al., 2014). In one clinical study, the cleaning efficacy of two interdental brushes with different bristle designs (straight interdental brush vs. waist-shaped brush) around teeth and implants was compared (Chongcharoen et al., 2012). As the point of interest in this study was the comparison of two similar tools only, no further conclusion could be drawn concerning other tools.

From the results of the present study, it can be clearly noticed that dental flosses in general were able to remove a major part of the artificial biofilm and reach very close the implant–abutment interface, especially around the ACD restorations. Nevertheless, in a previous study investigating the efficacy of different interproximal tools, it was recommended to use interdental brushes instead of flossing for interproximal cleaning. Here, it was shown that dental floss may be torn on exposed rough surfaces of implants, promoting plaque retention. Therefore, flossing was identified as a potential risk factor for peri-implant health (van Velzen, Lang, Schulten, & Ten Bruggenkate, 2016). However, this disadvantage with flossing could not be confirmed in the current study due to its *in vitro* design with non-exposed rough implant surfaces.

Due to the paucity of studies comparing the efficacy of different interproximal tools around implant restorations (Louropoulou et al., 2014), the results of studies investigating the efficacy of these tools around natural teeth were additionally put into consideration. In a recent meta-review, moderate evidence supporting the efficacy of interdental brushes on plaque removal and reduction of gingivitis was reported. On the other hand, there was only weak evidence supporting the use of dental floss, toothpicks, and oral irrigators (Salzer, Slot, Van der Weijden, & Dorfer, 2015). Interestingly, the results of our study showed that SF and DF were the most effective among all investigated tools. The reason here may be due to the ability to use the flosses very deep subgingivally in the test models, which may be unrealistic in patients.

Recently, the focus has shifted to power products to supplement oral health such as air and water flossers. Many studies reported the effectiveness of microdroplet flossers on the removal of interproximal plaque around teeth (Goyal, Lyle, Qaqish, & Schuller, 2013, 2015; Sharma, Lyle, Qaqish, & Schuller, 2012). In this *in vitro* study, the microdroplet flosser had in general the least cleaning efficacy among all investigated devices. When comparing the effect of this tool on the two different crown designs, a statistically significant difference in the cleaning efficacy could be noted for CCD, but the overall effect was relatively small. A reason for the low efficacy of this tool may be its different cleaning mechanism, as it is mainly designed to remove interproximal plaque by rapid bursting of pressurized water droplets and air through the interproximal spaces between teeth.

The last hypothesis regarding participant groups showed that dentists followed by dental hygienists and laypersons achieved the best cleaning efficiency. Interestingly, not more than 75% was removed even by the well-trained participants, that is, dentists and dental hygienists.

This *in vitro* study may not give an accurate representation of the clinical situation since variations and limitations exist in terms of accessibility, visibility, individual capability as well as type of gingiva,

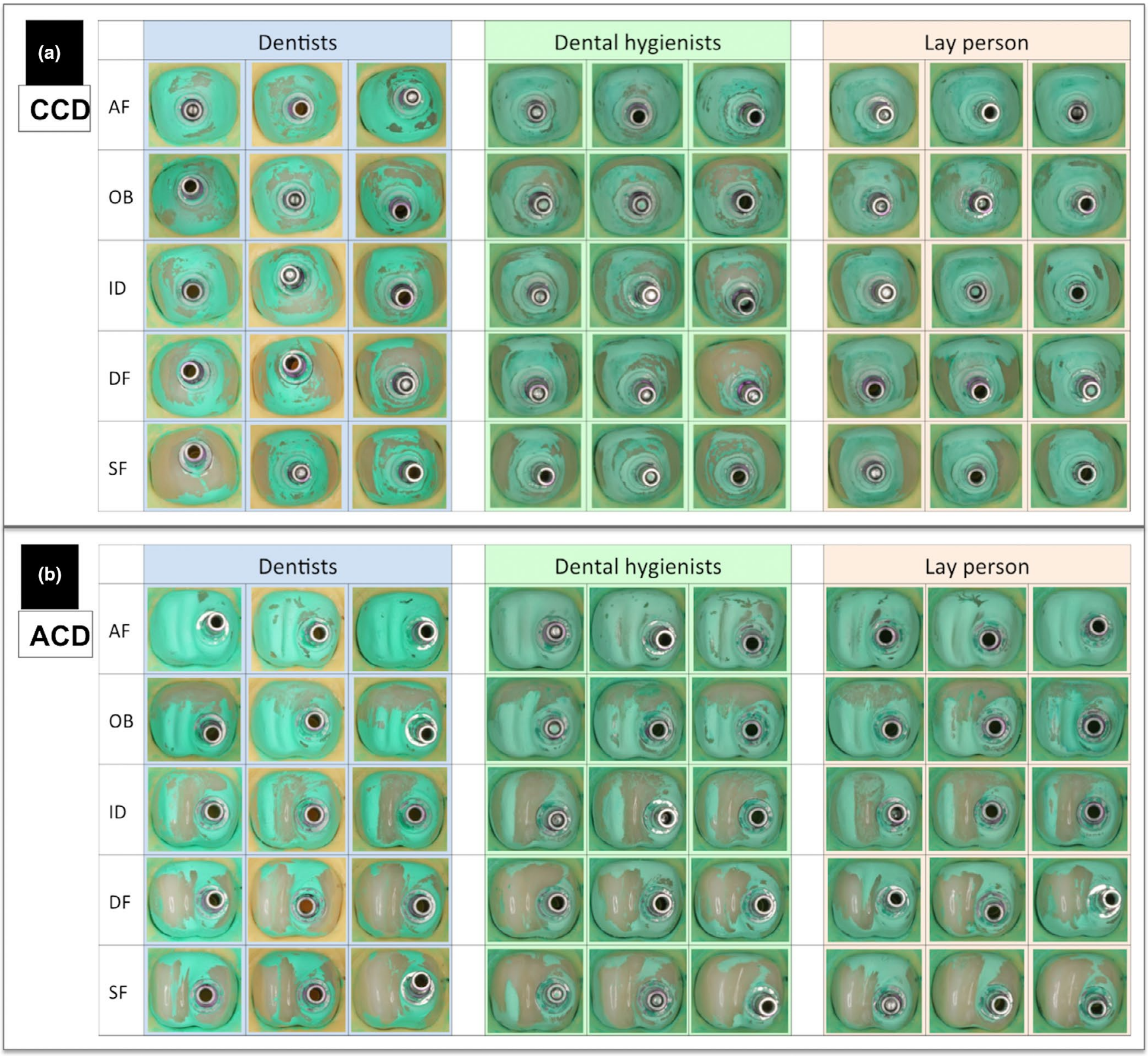

FIGURE 7 Visual assessment of cleaning ratio for basal (bottom) surfaces at CCD (a) and ACD (b). The figure shows a random selection of three samples from each of the n = 10 groups for each cleaning tool

amount and mechanical properties of the artificial dental biofilm. In the present study, a color agent was used to simulate the artificial biofilm. This simulation agent had to be optically detectable in order to achieve an optimal quantitative evaluation. With the use of occlusal spray, it was confirmed, as demonstrated in previous clinical studies (Salzer et al., 2015), that plaque could be more likely mechanically removed with cleaning tools than with irrigators. Moreover, the use and examination of real plaque would have required a complex, technically sensitive, and sterile condition (bench), which is very prone to inaccurate data (Sahrmann et al., 2013).

Other limitations include that tests were performed on models in phantom heads, which may have helped the participant in finding the ideal position in order to gain the best accessibility. This is not the case when patients perform their own oral hygiene care. On the other hand, the results can be comparable for disabled patients requiring assistance with their daily oral hygiene.

In spite of the limitations highlighted, this study moves us a step closer to replicate the feasibility of the different interproximal tools around the two crown designs in vivo. Therefore, further well-designed clinical studies have to be performed in order to strengthen the results of this study.

Within the limitations of this study, the following can be concluded:

- ACD allowed more removal of the artificial biofilm than CCD with Super floss, dental floss, and interdental brush.

- Flossing and interproximal brushing showed to be the most effective methods for interproximal removal of artificial biofilm.
- However, all types of cleaning devices investigated in this study were not effective in complete removal of artificial biofilm from the interproximal spaces.

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CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

Dr. Tuna and Dr. Bishti led the writing of the article and developed and supervised the practical part of the study. Ms. Kuhlmann did the practical part of the study. Ms. Sirazitdinova and Prof. Deserno analyzed the data and wrote the analysis paragraph. Prof. Wolfart conceived the idea and contributed to the authoring of the article.

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