Regarding the incidence of peri-implantitis, treatment of peri-implant diseases has become an increasingly pronounced challenge in modern dentistry.\textsuperscript{1–3} As a result, peri-implant diseases were included in the recent classification of periodontal diseases in 2018.\textsuperscript{4} There is a broad consensus that the onset of peri-implant mucositis and peri-implantitis that may possibly result from such is based on a plaque-induced inflammation of peri-implant tissues leading to clinical signs of bleeding on probing and increased pocket probing depths.\textsuperscript{5} In the case of peri-implantitis, progressive bone loss around the implant shoulder occurs, which is the main cause of later implant loss.\textsuperscript{1,4,6} The extent of this condition can be influenced by risk factors such as poor oral hygiene, presence or history of periodontitis, nicotine use, and irregular supportive implant therapy.\textsuperscript{5,7,8}

In Vitro Efficacy of Three Different Nonsurgical Implant Surface Decontamination Methods in Three Different Defect Configurations

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\textbf{Purpose:} Assessment of in vitro efficacy of three different nonsurgical implant surface decontamination methods in three peri-implant bone defect simulation models. \textbf{Materials and Methods:} A total of 180 implants were allocated to differently angulated (30, 60, and 90 degrees) peri-implant bone defect resin models, each covered by a mucosa mask. All implants were stained with indelible red color and assigned to one of the three defect models. In each simulated bone defect group, 20 implants were decontaminated for 2 minutes with a curette (CUR), sonic scaler (SOSC), or air-powder abrasion device (APA) with glycine powder. Photos were taken from both sides of each implant to measure the percentage of uncleaned implant surface area. Scanning electron microscopy (SEM) was used to assess the implant surface for morphologic damage. \textbf{Results:} Among the three defect angulations, a significantly different cleaning efficacy ($P < .001$) for each treatment method was found (30 degrees: CUR [67.33%], SOSC [62.70%], APA [39.33%]; 60 degrees: CUR [61.59%], SOSC [54.31%], APA [23.91%]; 90 degrees: CUR [66.82%], SOSC [55.77%], APA [28.03%]). SEM did not show any considerable surface damage after APA treatment in comparison with after CUR or SOSC. \textbf{Conclusion:} Air-powder abrasion proved to be the most efficient nonsurgical treatment device for each type of defect in this in vitro model with the least noticeable surface change. No decontamination method resulted in complete cleaning of the color remnants on the implant surface. \textit{Int J Oral Maxillofac Implants} 2021;36:271–280. doi: 10.11607/jomi.8864

\textbf{Keywords:} abrasion, decontamination, dental air, dental implant, peri-implantitis

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bacterial biofilms—exist to date. Furthermore, a range of treatment approaches for implant surface decontamination (eg, hand instruments, sonic scaler, lasers, photodynamic therapy, air-powder abrasion devices) are available that, depending on the implant surface, lead to more or less effective results.16

Explantation as the ultimate treatment option in the case of peri-implantitis often results in a bone defect followed by the need for prosthetic rehabilitation. In particular, patients prefer an attempt to maintain diseased implants by means of effective surface decontamination.

Surgical approaches, as examined in vitro,17–19 seem to be more clinically effective in more advanced peri-implant bone defects. Nonsurgical procedures did not achieve predictable results, as accessibility is impeded.15,16,19,20 Nevertheless, they are discussed in the literature,19 since they are less invasive than surgical procedures, which are not justified for every radiologically recognizable peri-implant bone defect. Furthermore, similar to periodontal bone defects,22 nonsurgical submucosal instrumentation in peri-implant bone defects always precedes surgical intervention by being less complex and expensive.23

Data concerning nonsurgical treatment approaches in peri-implant bone defects that focus on the efficacy of surface decontamination are rare,21 and comparable confirmatory studies using other implant systems and alternative decontamination devices are missing. Therefore, this study compared three common implant surface decontamination methods using a repeatedly proven and differently angulated in vitro model in order (1) to expand available data on cleaning efficacy of nonsurgical therapy options, (2) to confirm existing results, and (3) to obtain a comparison of the efficacy in a surgical in vitro simulation while following a similar protocol.18,19 Unlike in previous investigations, a different implant system and alternative implant surface decontamination devices were deliberately chosen.21 The null hypothesis was that all surface decontamination modalities will show statistically different outcomes in terms of the percentage of color remnants on the implant surface.

MATERIALS AND METHODS

Implant Preparation and Model
The study was based on the setup by Ronay et al and also follows approaches from Sahrmann et al.17,21 Moreover, the setup of the study was almost identical to that of Keim et al.18 yet differed by using a different implant system ([13 × 4.2 mm] OsseoSpeed EV 4.2S, Dentsply Sirona Implants) and by applying a nonsurgical therapy approach instead of a surgical one (Fig 1).

The implant consisted of a small 0.3-mm machined, beveled surface in the most coronal area and two rough surfaces: (1) a microthread in the adjacent part (thread height: 3.3 mm, thread distance: 0.22 mm) that remained still in the coronal half of the implant and (2) a macrothread located in the apical part (thread height: 9.7 mm, thread distance: 0.66 mm, thread depth: 0.3 mm). The machined implant surface (0.3 mm) ultimately was no longer distinguishable from the rough surface (12.7 mm) due to the relatively small proportion. The rough implant surface was created by blasting the surface with titanium dioxide particles and treating it with fluoride ions, resulting in a mean surface roughness of 1.5 µm.24

Implants in the 30- and 60-degree defects were placed 13 mm (complete rough implant surface) into the models to simulate a supracrestal position of the machined surface (0.3 mm). The suprasseous (90-degree) defect simulation resulted in a supracrestal position of the machined and rough implant surfaces.17,18,21 Each model simulated a 6-mm-deep bone defect (Fig 2), which was covered with a reusable mucosa mask after implant insertion. The mask was individually manufactured using a nontransparent duplicating silicone (Adisil rosé 1:1; Siladent) to prevent visual control of the cleaning procedure (Fig 3).19,21

Simulation Procedure
A total of 180 implants were enrolled for the simulation. Each nonsurgical cleaning method was tested on 20 of the 60 implants per defect angle. The following devices for nonsurgical surface decontamination were used (in accordance with Keim et al18; Fig 3):

Fig 1 Lateral view of the bone defect models (intraosseous: [a] 30 degrees, [b] 60 degrees; supraosseous: [c] 90 degrees) without mucosa mask.
1. Langer steel curette SL 1/26 (Curette: CUR [Hu-Friedy]).
2. Ti-Max S970 Air Scaler (Sonic scaler: SOSC [NSK Europe]) with a steel tip (S20, NSK) and 20 mL/min of water ejection.
3. Perio-Mate (NSK) air-powder abrasion device with glycine powder (Air-powder abrasion: APA [Perio-Mate Powder, NSK]) and attached Perio-Mate nozzle tip (NSK) using the medium setting for powder emission and water ejection. The nozzle tip was changed after each application.

All implants were cleaned for 2 minutes by the same operator (C.C.) using an individually selectable working distance and angle. The mucosa mask and implant were removed after each instrumentation to wash off dissolved color remnants with a gentle air–water rinse for 10 seconds.\(^{17,18}\)

**Photo Documentation and Analysis**

Photo documentation (Fig 4) was performed in accordance with Keim et al\(^ {18}\) by one examiner (PI) using standardized illumination and parameters (31.4-cm distance, ISO 100, aperture f/32, exposure time of 1/250 seconds).\(^ {17,18}\) Implants were removed individually from the model and fixed (Implant Driver EV Long, Dentsply Sirona Implants) in an individually fabricated and nonmovable holder. Then, both sides (180 degrees) of the implants were digitally photographed in a uniformly illuminated photo tent (Proxistar) with ring flash (Canon ring flash, MR-14).

Due to a simplified workflow, the determination of color remnants was carried out using software deviating from Keim et al.\(^ {18}\) All 360 resulting photos were analyzed for color remnants by two examiners (PI and C.C.) using photo-editing freeware (ImageJ 1.52a, National Institutes of Health; https://imagej.nih.gov/ij/). Therefore, a consistent region of interest (ROI) for each side (180 degrees) of the implant was defined previously (H.P.). The ROI (output in pixels) corresponded with the implant surface of the respective site without the apical part (7 mm), which was included circumferentially in all models. Then, the relevant treated implant surfaces could be easily selected by ROI. The red-colored parts of the ROI were marked and analyzed. As a result, the number of pixels of the red-colored remnants was displayed. This number was multiplied by 100 and divided by the total number of pixels in the ROI, resulting in the percentage (%). This procedure was repeated for the second side of the implant. Finally, the means of both percentages were calculated to obtain a total value of color remnants as a percentage (%) of the completely treated implant surface. Basic picture settings (contrast, sharpness, brightness) were not changed.

Additionally,\(^ {18}\) scanning electron microscopy (SEM; Philips XL 30 with lanthanum hexaboride cathode,
20 kv, 10-mm distance, Philips) of the surfaces of microthreads and macrothreads of an untreated implant (reference) and one treated implant for each treatment modality were exemplarily performed (C.R.; magnification 1 × 1,000 and 1 × 10,000; Figs 5 and 6).

Statistical Evaluation
The statistical evaluation followed the protocol reported by Keim et al. The percentage of uncleaned surface was calculated for each implant. Color-remnant determination was carried out by two examiners (P.I. and C.C.) for each implant. For further analysis, the mean value of each measurement was calculated.

Descriptive data (mean, median, lower/upper quartile, interquartile range [IQR] and standard deviation values) were analyzed for treatment modalities and defect angulations. Group comparisons were carried out using the Kruskal-Wallis test for nonnormally distributed data (Kolmogorov-Smirnov test). By defining a $P$ value < .001 as the significance level, multiple testing (36 comparisons) was addressed. Pearson’s correlation coefficient was calculated for the interindividual agreement of the photo analysis. Statistical analysis was performed using computer software (SPSS Statistics 24 software package, IBM).

The study was planned in accordance with the Enhancing the Quality and Transparency of Health Research (EQUATOR) guidelines.

RESULTS
The color-remnant determination by two examiners (P.I. and C.C.) showed a significantly positive, high degree of agreement ($|r| = 0.890; P < .0001$).

The cleaning efficiency showed significantly different results ($P < .001$) for each decontamination method within each defect angulation. None of the implant surfaces was completely cleaned (0%). Color remnants on the lower 7 mm of the implants can be explained by the fact that they were not accessible for cleaning because this part of each implant was surrounded by acrylic...
glass (Fig 2). APA showed the lowest amount of color remnants with 40.31% (IQR: 6.32) for the 30-degree, 21.78% (IQR: 21.17) for the 60-degree, and 26.77% (IQR: 15.69) for the 90-degree defect simulation, respectively (Table 1 and Fig 7). This was followed by SOSC, with 64.50% (IQR: 6.15) for the 30-degree, 53.67% (IQR: 6.57) for the 60-degree, and 56.45% (IQR: 3.38) for the 90-degree defect simulations. CUR exhibited the lowest cleaning potential with 67.20% (IQR: 4.30) for the 30-degree, 61.89% (IQR: 2.37) for the 60-degree, and 66.64% (IQR: 3.34) for the 90-degree defect simulations. Since all differences between the decontamination methods were statistically significant (P < .001), the null hypothesis was accepted. All treatment modalities revealed significantly lower color-remnant values for the 60-degree defects compared with the 30-degree defects (P < .001). Color remnants for the other angulations differed significantly (P < .001) between the 30-degree and 90-degree defects for both SOSC and APA and between the 60-degree and 90-degree defects for CUR (Table 1).

The greatest difference in cleaning efficacy between the cleaning devices when considering all defect angulations (Table 1) was apparent between CUR and APA as follows: 27.92% (IQR: 4.92) for 30 degrees, 39.96% (IQR: 19.14) for 60 degrees, and 40.91% (IQR: 16.47) for 90 degrees. This was followed by that between SOSC and APA: 23.47% (IQR: 10.98) for 30 degrees, 35.99% (IQR:...
The smallest difference was observed between CUR and SOSC when considering defect sizes. SEM confirmed the complexity of the surface morphology of the selected implant system. Cleaning with APA showed in the area of the microthreads and macrothreads a smoother and more rounded implant surface without any considerable surface damage (Figs 5 and 6). In contrast, in the 1,000× magnification, SOSC and CUR showed implant surface damage leading to clear destruction of the surface structure. Compared with the reference, the change in topography seemed to be more pronounced for CUR than for SOSC (CUR > SOSC > APA; Figs 5 and 6). This difference cannot be seen consistently at a 10,000× magnification.

### DISCUSSION

This study was carried out as a follow-up project to that by Keim et al to generate data on the efficiency of nonsurgical implant surface decontamination and to

#### Table 1

<table>
<thead>
<tr>
<th>Defect angulation</th>
<th>30 deg</th>
<th>60 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentile (%)</td>
<td>P (30–60 deg)</td>
</tr>
<tr>
<td>CUR</td>
<td>Min (%)</td>
<td>Max (%)</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>62.73</td>
<td>71.97</td>
</tr>
<tr>
<td>P (CUR-SOSC)</td>
<td>&lt; .001*</td>
<td></td>
</tr>
<tr>
<td>SOSC</td>
<td>54.85</td>
<td>67.82</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>62.70 ± 3.76</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>P (SOSC-APA)</td>
<td>&lt; .001*</td>
<td></td>
</tr>
<tr>
<td>APA</td>
<td>24.89</td>
<td>49.90</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>39.33 ± 5.55</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>P (APA-CUR)</td>
<td>&lt; .001*</td>
<td></td>
</tr>
<tr>
<td>CUR - SOSC</td>
<td>–3.18</td>
<td>14.06</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>4.63 ± 5.37</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>P (CUR-SOSC – SOSC-APA)</td>
<td>&lt; .001*</td>
<td></td>
</tr>
<tr>
<td>SOSC - APA</td>
<td>10.62</td>
<td>37.40</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>23.38 ± 7.12</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>P (SOSC-APA – CUR-APA)</td>
<td>.058</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>CUR - APA</td>
<td>18.46</td>
<td>44.08</td>
</tr>
<tr>
<td>Mean ± SD (mm)</td>
<td>28.01 ± 5.44</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>P (CUR-APA – CUR-SOSC)</td>
<td>&lt; .001*</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented separately for different treatment methods and defect angulations. N = 20 for each treatment method in each defect angulation. *Statistically significant.

Fig 7 Percentage of color remnants according to different treatment modalities for each type of defect.
Iatrou et al compare it with the already-simulated surgical therapy approach.\(^{18}\) The objective of this study was to compare three different implant surface decontamination methods in different in vitro defect models (30, 60, and 90 degrees). Regardless of the nonsurgical treatment approach and the defect angulation, residual color remnants were detected on all implant surfaces. Among the three investigated methods, APA attained the best results. While all cleaning methods differed significantly in terms of their cleaning efficacy (\(P < .001\)), the differences between defect angulations were not consistently significant.

As already discussed in previous studies\(^{18}\) that adopted the same cleaning time, the use of rigid instruments (curette, sonic scaler with universal tip) for the circumferential decontamination of rough surfaces in differently angled defects is a challenge by itself. Compared with other studies,\(^{15}\) the cleaning procedure in the present study was less efficient for all defect angulations and decontamination methods used. This difference may be due to the difference in the simulated approach in the prior research (surgical open-access approach) compared with this study (nonsurgical flapless approach), which facilitates different levels of visual control and surface accessibility. Furthermore, different types of implants (bone- and tissue-level) were used, which could also have influenced the results due to their variable surface properties. In addition, compared with the study by Keim et al, the detection method of color remnants on the implant surfaces was changed in this investigation to simplify the workflow and make it more effective, which makes the comparison more difficult to complete. At the same time, a high level of reproducibility of the method used in this study could be demonstrated (\(|r| = 0.890; P < .0001\) for two dentists with different professional experience (3 and 7 years). In principle, it can be deduced from this comparison for the clinic that, in the case of an initially 6-mm-deep bone defect, a surgical procedure is preferable to a nonsurgical procedure in terms of cleaning efficiency. Moreover, the best possible results would be expected from using APA.

<table>
<thead>
<tr>
<th>Defect angulation</th>
<th>Percentile (%)</th>
<th>(P)</th>
<th>Percentile (%)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 deg</td>
<td>25th</td>
<td>50th (Median)</td>
<td>75th</td>
<td>(30–60 deg)</td>
</tr>
<tr>
<td></td>
<td>60.22</td>
<td>61.89</td>
<td>62.59</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td></td>
<td>50.91</td>
<td>53.67</td>
<td>57.48</td>
<td>.160</td>
</tr>
<tr>
<td></td>
<td>14.32</td>
<td>21.78</td>
<td>35.40</td>
<td>.204</td>
</tr>
<tr>
<td>90 deg</td>
<td>4.86</td>
<td>8.60</td>
<td>10.79</td>
<td>.317</td>
</tr>
<tr>
<td></td>
<td>16.99</td>
<td>35.99</td>
<td>38.76</td>
<td>.234</td>
</tr>
<tr>
<td></td>
<td>27.07</td>
<td>39.96</td>
<td>46.21</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

Data are presented separately for different treatment methods and defect angulations. \(N = 20\) for each treatment method in each defect angulation.

*Statistically significant.
In a similarly designed in vitro study also simulating a nonsurgical therapy approach by applying a cleaning time of 2 minutes for each implant, higher values for surface decontamination with curettes (30 degrees: 76.50% ± 3.2%, 60 degrees: 73.65% ± 5.34%, 90 degrees: 73.95% ± 5.23%) and ultrasonic scaler (30 degrees: 74.10% ± 8.99%, 60 degrees: 66.25% ± 5.89%, 90 degrees: 60.45% ± 4.54%) were recorded compared with the present study. Meanwhile, decontamination using an air-powder abrasion device (30 degrees: 40.15% ± 10.40%; 60 degrees: 40.30% ± 7.12%; 90 degrees: 21.20% ± 8.96%) was less efficient in two (30 and 60 degrees) but more efficient in one (90 degrees) of the defect models. These differences, given that bone-level implants were used in both studies, may be due to different implant types with varied macrostructures and microstructures. Ronay et al used implants with etched and sandblasted surfaces, resulting in a significant amount of mean surface roughness (2.35 ± 0.25 µm). Additionally, the system used had a wider thread distance (1.0 mm), a 1.0-mm-high machined implant collar, and deeper threads (0.35 mm), making the apically facing site significantly more difficult to clean than the area between the threads or the coronally facing site. The implant type selected in this study had a lower surface roughness (1.5 µm, modified by blasting with titanium dioxide particles and with fluoride) and a microthread, which formed approximately 50% of the analyzed area (Figs 1 and 2); the very small thread height and distance of this system possibly made cleaning more efficient. It is not possible to make a final statement about the impact of the implant surface due to the different results observed.

Notably, there were also differences in the instruments used for surface treatment in this study. Ronay et al used an ultrasonic scaler and an air-powder abrasion device with a differently dimensioned nozzle tip. The latter could explain the different results for APA. In this study, a more delicately dimensioned nozzle tip was used, which could possibly better reach the apical regions of the implant surface in the intraosseous defects (30 and 60 degrees), whereas in the supraosseous defect (90 degrees), it could lead to less efficient results due to the low rigidity and the greater pressure of the mucosal mask present while the examiner was holding the model in their hand. The authors assume that the different materials of the mucosa masks in both studies also had an impact on the results. However, the use of a nonsurgical approach in everyday clinical practice is not contraindicated. The results show that a cleaning effect is achieved, albeit one that is worse than that achieved with the surgical approach, which—if only a few sites are affected—may not be economical or even feasible in multimorbidity patients. However, this procedure can be integrated well into the nonsurgical periodontal therapy of teeth. The best cleaning results would again be achieved with the application of APA.

Within the present investigation and similar to the previous surgical simulation, the differences in cleaning efficacy were more pronounced between treatment modalities than between defect types (Table 1). The results of this study consistently showed, as was demonstrated with the surgical in vitro simulation, that the most effective cleaning occurred in the 60-degree defect and the most ineffective cleaning occurred in the 30-degree defect for all treatment methods. While it seems plausible that the lowest levels of cleaning efficacy occur in the model with the steepest defect angle, the pairing of the highest efficacy and the 60-degree defect is more difficult to explain. The lack of a significant difference to the 90-degree defect between SOSC and APA underlines the greater approximation of the wider infra-alveolar defect to the supraosseous defect than to the 30-degree defect. A possible reason for this could be that the 60-degree defect is the largest volume defect that fills up with water, more than the 30-degree or the 90-degree defect, during cleaning with APA and SOSC. Consequently, the water is “activated” by the frequency of SOSC and reflected by the defect walls and the mask during the cleaning process, which also ensures a cleaning effect. Furthermore, the vibration of the mucosa mask resulting from both methods (SOSC and APA) may influence the outcome. The better results for CUR may be due to the rigidity of the mucosal mask, which is supported circumferentially by simulated bone walls compared with the 90-degree defect and is therefore not subject to the uneven pressure of the hand (90 degrees) during in vitro cleaning.

For the practitioner, this means that deep, narrow defects in particular are less efficient to clean. Therefore, if possible, these should be identified by radiologic examination and subjected to a surgical rather than nonsurgical APA procedure.

In addition, the superiority of the cleaning efficacy of APA over both CUR and SOSC was demonstrated. This confirms earlier results and assumes that the application of APA on the complex rough implant surface requires lower manual skills than the application of CUR or SOSC. Further variations in the study setup, such as immersion and drying times, which are not reported in more detail by Ronay et al, may have influenced the results. Finally, the cleaning time of 2 minutes was probably not enough.

The present study presupposed that it is possible to remove the suprastructure from the implants to ensure more straightforward accessibility of the implant surface. However, leaving the suprastructure may have resulted in poorer results due to the limited...
accessibility.\textsuperscript{28} Still, it must be considered that the removal of a cemented suprastructure is not always easily possible in everyday clinical practice. It can only be assumed that screw-retained suprastructures, which are easy to remove, enable this optimal access with the corresponding cleaning efficiency more easily than cemented suprastructures do.

SEM images of this study confirm the findings of other investigations showing damage of implant surface morphology following the application of steel curettes and (ultra)sonic scalers with universal tips.\textsuperscript{17,18,21,29,30} In contrast, the application of APA with glycine(-based) powder changed the surface morphology by facilitating a kind of smoothing but did not result in the additional edges and unevenness shown in the 1,000× magnification (Figs 5 and 6). In the 10,000× magnification, this was also not apparent throughout because the destroyed area may not have been adjusted exactly.\textsuperscript{18} Additionally, this enlargement caused blurring in the SEM images due to the increased color remnants that could partly be penetrated by the electrons, which led to an unsharpened layer.

The minor surface change on implants after APA application corroborates the results of other studies\textsuperscript{17,18,21,31} and was confirmed by a current review on the in vitro effect of APA on implant surface damage.\textsuperscript{27} This concludes that APA is highly effective in cleaning without causing serious surface damage. Therefore, APA is proposed for adoption into clinical use for decontamination of peri-implant defects to maintain the surface structure and morphology, but it is also emphasized that complete cleaning is not achievable either surgically or nonsurgically. Thus, there is a short-term positive development of the clinical results, but the long-term effect has to be questioned further\textsuperscript{32} due to the limitation in restoring the biocompatibility of the surface.\textsuperscript{27} Three systematic reviews on the in vivo nonsurgical use of APA conclude that it is effective in plaque reduction\textsuperscript{33} and has a benefit in the therapy of peri-implant mucositis and peri-implantitis.\textsuperscript{16,34}

Transferring knowledge from classical periodontology to the peri-implant situation to achieve the highest possible efficiency in the removal of bacterial biofilm in combination with low surface damage is probably the key, which in the long term would lead to a stable situation without clinical signs of inflammation around implants.

From a clinical point of view, the following consequences after implant surface decontamination would be desirable\textsuperscript{4}: (1) an increasing likelihood of stopping peri-implant disease progression and no further increase of probing depths and/or clinical signs of inflammation (bleeding on probing) and (2) a radiologic filling of peri-implant bone defects.

Since none of the treatment modalities ensured a 100% decontaminated implant surface, a degree of bacterial residual colonization has to be assumed. This makes the aforementioned results less likely and suggests that the methods presented in the nonsurgical approach should possibly be combined with further therapy methods and/or a surgical approach. Nevertheless, if a nonsurgical approach is chosen, APA should be the first choice in the case of a moderate, 6-mm-deep bone defect according to the results of the present study. An expanded surgical approach using APA would presumably yield better clinical results, but it is important to note that, to the best of the authors’ knowledge, the surgical use of APA is currently considered off-label use.

However, this study has limitations and is not completely applicable to clinical settings without additional confirmation from clinical studies. Biofilm imitation by color in an in vitro model without simulating further oral cavity–specific influences and free defect accessibility is a limitation of this study. Nevertheless, this model\textsuperscript{18} and the use of color as “artificial plaque”\textsuperscript{17,18,21,31} have already been established in earlier investigations and facilitate comparisons between these studies. Further, the rigidity of the mucosa mask may differ from the oral mucosa, which may influence the results. The different cleaning methods, the defect morphology covered by a simulated peri-implant soft tissue, the implant surface, and the skills of the practitioner all correspond to a real clinical situation. The strength of the color adherence on the implant surface differs from that of real bacterial plaque with steady salivation, but this would probably shift all cleaning efficacy values in the same direction. Therefore, the differences in the cleaning efficiency of this in vitro simulation are nevertheless significant. The evaluation of the photographs from a single angle did not allow for a detailed differentiation of color remnants on the apically and coronally facing sides of the threads.\textsuperscript{26,31} Although three decontamination methods were simulated for different defect angles, no statement can be made about different defect depths.

**CONCLUSIONS**

Within the limitations of this study, APA is, in a nonsurgical in vitro model—in accordance with previous results on a surgical simulation\textsuperscript{18}—the most efficient (in descending order: APA, SOSC, and CUR) treatment method for each type of defect without causing considerable surface damage. Nevertheless, a complete degree of surface decontamination was not achieved with any instrument.
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