

Influence of scaling procedures on the integrity of titanium nitride coated CAD/CAM abutments

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PURPOSE. To determine the extent of treatment traces, the roughness depth, and the quantity of titanium nitride (TiN) removed from the surface of CAD/CAM abutments after treatment with various instruments. **MATERIALS AND METHODS.** 12 TiN coated CAD/CAM abutments were investigated for an *in vitro* study. In the test group (9), each abutment surface was subjected twice (150 g vs. 200 g pressure) to standardized treatment in a simulated prophylaxis measure with the following instruments: acrylic scaler, titanium curette, and ultrasonic scaler with steel tip. Three abutments were used as control group. Average surface roughness (Sa) and developed interfacial area ratio (Sdr) of treated and untreated surfaces were measured with a profilometer. The extent of treatment traces were analyzed by scanning electron microscopy. **RESULTS.** Manipulation with ultrasonic scalers resulted in a significant increase of average surface roughness (Sa, $P < .05$) and developed interfacial area ratio (Sdr, $P < .018$). Variable contact pressure did not yield any statistically significant difference on Sa-values for all instruments ($P = .8$). Ultrasonic treatment resulted in pronounced surface traces and partial detachment of the TiN coating. While titanium curettes caused predominantly moderate treatment traces, no traces or detectable substance removal has been determined after manipulation with acrylic curettes. **CONCLUSION.** Inappropriate instruments during regular plaque control may have an adverse effect on the integrity of the TiN coating of CAD/CAM abutments. To prevent defects and an increased surface roughness at the transmucosal zone of TiN abutments, only acrylic scaling instruments can be recommended for regular maintenance care. [J Adv Prosthodont]

KEYWORDS: Titanium nitride; Abutments; Scaling; Surface roughness; Scanning electron microscopy

INTRODUCTION

Achieving natural harmony between implant-prosthetic components and the surrounding soft tissues is challenging for the restorative team. The implant abutment design, its material and color seem to be of decisive importance for ensuring an esthetic mucogingival architecture.^{1,2} In the past, there have been two main types of abutments available for restoring implants: conventional titanium stock abutments, traditionally supplied by dental implant manufacturers to match their respective implant system, and custom cast abutments. Recently, novel computer-aided designed (CAD), computer-aided manufactured (CAM) abutments of various

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materials have been introduced. CAD/CAM abutments can be custom designed to re-create the desired emergence profile and supporting crown orientation, facilitating the formation of anatomical mucosal topography and coronal contours for prosthetic replacement.^{3,4} Although very stable from a technical point of view, all abutments made of commercially pure titanium have been reported to cause a greyish discolouration of the surrounding soft tissues, compromising the esthetic outcome in the anterior region.^{5,6} This discolouration is most apparent in patients with a thin gingival biotype that is incapable of blocking reflective light from the metallic abutment surface.⁵ Due to their tooth-like colour and potential biologic advantages, ceramic abutments have been promoted to achieve better mucogingival esthetics.⁷⁻⁹ Nevertheless, the esthetic benefit of all-ceramic abutments needs to be carefully balanced against the reduced fracture resistance compared to titanium abutments.¹⁰ All-ceramic abutments cannot be machined to the same degree of precision as metal abutments. Recent studies have shown that zirconia abutments have a marginal misfit to the implant that might cause screw loosening, micromotion, wear of the implant-abutment interface, and increased size of the marginal gap subject to bacterial colonization.¹¹⁻¹⁴ In addition to commercially pure titanium abutments, clinical studies have reported promising results with surface modifications of titanium, such as coatings of CAD/CAM abutments with titanium nitride (TiN).^{15,16}

The TiN-coating is created by a plasma coating process in which titanium and nitrogen ions are combined with TiN, and then molecularly bonded with the titanium substrate of the abutment. Reports have characterized TiN as having a high chemical inertness, low friction coefficient, and good biocompatibility.^{17,18} TiN has excellent infrared reflectivity properties, reflecting in a spectrum similar to elemental gold, achieving a warm esthetic tone under the mucosa because of its gold shaded hue.¹⁹ Less color difference of the peri-implant mucosa has been reported with gold-shaded and titanium nitride-coated CAD/CAM abutments.^{15,20,21} In addition, TiN coatings seem to have a beneficial effect on antibacterial activity inhibiting the formation of micro-

al plaque, minimizing the adverse effects of peri-implantitis on implant longevity. It reduces bacteria, diminishes its metabolic activity, adhesion and proliferation but simultaneously maintains the biological affinity of titanium surfaces towards bone cell precursors and promotes human gingival fibroblast adhesion.^{18,22-24} In light of this, antibacterial activity is a desirable property while, especially for an abutment, enhanced abrasion resistance against scaling treatments is wanted to maintain the surface finish of the abutment. The surface properties of implant components at a gingival level have a decisive impact on the long term success of dental implants. Surface roughness beyond a threshold of 0.2 μm was found to be unsupportive in the prevention of plaque accumulation.^{25,26} An ideal transmucosal implant surface should be smooth, in order to allow the formation of an epithelial seal that prevents plaque accumulation.²⁵⁻²⁷ However, inappropriate instruments during regular maintenance therapy and plaque control may have an adverse effect on the surface integrity and biocompatibility of TiN-coated implant abutments.²⁸ Therefore, the aim of this *in vitro* study was to investigate the extent of treatment traces, surface roughness (Sa, in μm) and developed interfacial area ratio (Sdr, %) of TiN CAD/CAM abutments after treatment with various implant prophylaxis instruments.

MATERIALS AND METHODS

A total of 12 titanium nitride coated (TiN) CAD/CAM implant abutments were virtually designed and centrally manufactured (ATLANTIS GoldHue, Dentsply Sirona Implants, Mölndal, Sweden). The master cast of a clinical case in which the left maxillary first molar had been replaced by an implant restoration served as model of origin. The emergence profile of the peri-implant mucosa had been pre-conditioned by means of a temporary implant-supported single crown. The abutment and outer geometry were designed to allow placement of the crown margin slightly below the mucosa, following its scalloped anatomy. All specimens underwent a standardized ultrasonic cleaning procedure according to Gehrke *et al.*²⁹ (Fig. 1). The samples

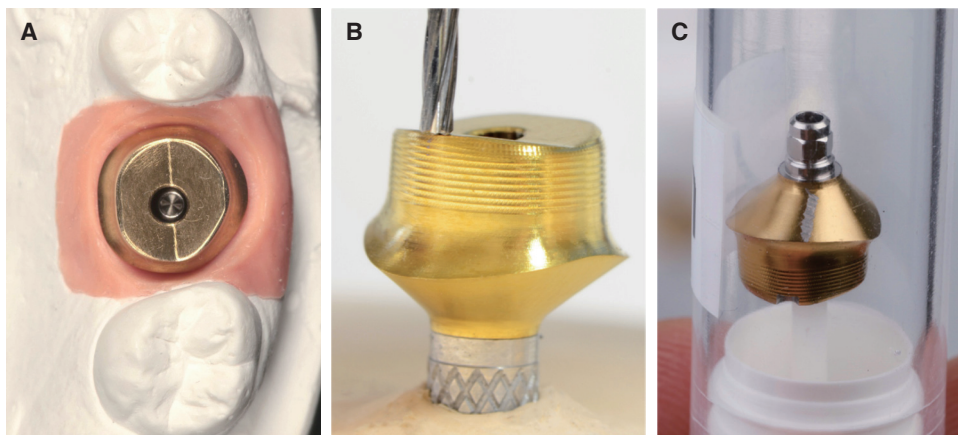


Fig. 1. TiN-coated CAD/CAM test abutments (ATLANTIS GoldHue, Dentsply Sirona Implants, Mölndal, Sweden): (A) On master-cast; (B) prior to scaling; and (C) stored in contactless container after scaling. Detachment traces are clearly visible at abutment shoulder.

were cleansed three times in an ultrasonic bath at 60°C for 10 minutes each. A resin nano ceramic (RNC) crown (Lava Ultimate, 3M ESPE, Neuss, Germany) was CAD/CAM produced (Cerec 3D, Sirona Dental Systems GmbH, Bensheim, Germany) and fixed on each abutment with a low-viscous silicone (Fit Checker Advanced, GC Corporation, Tokyo, Japan) prior to testing. It was refrained from cementing the crown in order to avoid surface alterations of the abutment shoulder due to undetected cement remnants.

For the present *in vitro* study the abutment-crown assemblies (12) were randomly divided into four groups of three samples each (3 test groups/ 1 control group).

In the test groups, three assemblies each were instrumented for 20 strokes with 150 g contact pressure at the labial aspect and 200 g at the oral aspect at the submucosal TiN-abutment shoulder (two 5 × 5-mm test fields on each abutment) with the following instruments: group 1: acrylic scaler (Hu Friedy Mfg. Co., LLC, Frankfurt); group 2: titanium curette (Hu Friedy Mfg. Co., LLC, Frankfurt); and group 3: steel tip on ultrasonic scaler at 30 kHz (Cavitron Plus, Hager & Werken, Dentsply, Duisburg, Germany). Three other abutment samples were not treated and used as a control group. The *in-vitro* scaling of the abutments have been carried out in a custom-made device in order to allow for controlled, standardized conditions (Fig. 2).²⁸ The abut-

ment-crown assemblies were connected to the compatible implant analogs (XiVE D 4.5 mm, Dentsply Sirona Implants, Mannheim, Germany) and mounted into the test set-up. A rail mechanism allowed for horizontally defined sliding, simulating the movements of instruments during scaling with a defined pressure (150 g / 200 g).

The test and control abutments were examined for average surface roughness (Sa) and developed interfacial surface area ratio due to texture (Sdr) by means of profilometric focus-variation microscopy (Infinite Focus Standard G4, Alicona Imaging GmbH, Graz, Austria). Treatment traces were analyzed by scanning electron microscopy (SEM) (Phenom ProX, PhenomWorld B.V., Eindhoven, Netherlands). The magnifications of the test and control fields were 1,000× and 5,000× times. The quality of the treatment traces on the abutment shoulder was classified by 3 independent investigators who, prior to study initiation, were calibrated for intra- and inter-examiner reproducibility using duplicate measurements of a minimum of 30 treated surfaces. These investigators classified the treatment traces using 3 grades: none, moderate, and pronounced. The untreated TiN-abutment surfaces served as controls.

For continuous variables, mean and standard deviation of the individual values were calculated. Frequency distributions were used to characterize categorical variables. Estimation of inter-rater agreement for the toolmark ratings of different raters were executed by calculating Cohens Kappa coefficient. Mann-Whitney-U-Test and Kruskal-Wallis H-Test were used to compare two (e.g. contact pressure 150 g vs. 200 g) or more than two (e.g. test and control groups) independent groups for continuous variables (e.g. Sa). In case of categorial comparisons (e.g. test and control groups vs. coating displacement), Pearson's chi-squared test was applied. Statistical analysis was carried out using the program packages STATISTICA (STATSOFT, Tulsa, OK, USA, version 9.1) and BiAS (Epsilon-Verlag, Frankfurt, version 11.02). Significance was set at $P < .05$.

RESULTS

Descriptive characteristic variables for the average surface roughness (Sa, in μm) and developed interfacial area ratio (Sdr, %) according to instrumentation is shown in Table 1 and Table 2. A pairwise comparison of treatment categories is presented in Table 3 for recorded Sa values. Profilometric images of the TiN-surfaces with various treatments showed differences depending upon the given treatment (Fig. 3). Manipulation with ultrasonic scalers resulted in a significant increase of average surface roughness (Sa, $P < .05$). Treatment group comparison proved likewise an increase of developed interfacial area ratio contributed by the texture of TiN-surfaces manipulated with ultrasonic instruments.(Table 2) Variable contact pressure did not yield any statistically significant difference on Sa-values for all instruments.(Table 3) The quantitative evaluation of treatment traces by SEM analysis revealed major disparities (Fig. 4). After instrumentation with ultrasonic scalers, all examiners classified the

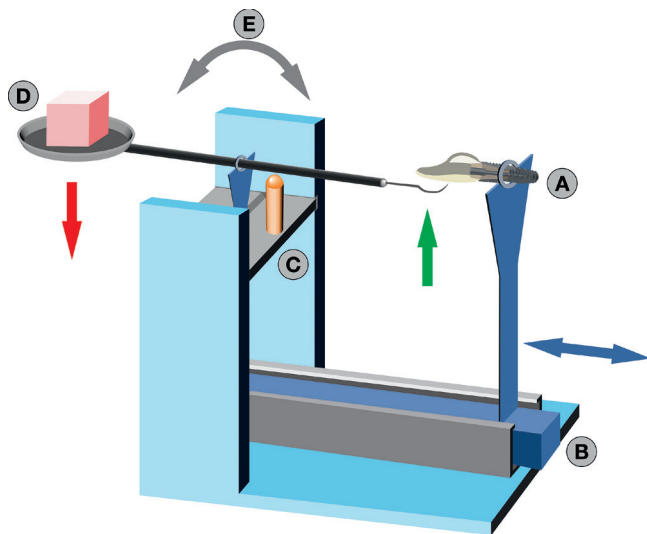


Fig. 2. Schematic test set-up: The TiN abutment-crown assembly was connected to an implant analog (A) and fixed in a horizontal rail mechanism (B). The handle of the scaling instrument was transversely mounted to a metal plate of the test construction, relative to the longitudinal axis of the handle (C). A weight (D) of 150 g / 200 g ensured a defined pressure of the working tip of the scaler at the abutment shoulder during horizontal sliding. Continuous contact of the working tip was provided by a tilting mechanism (E). Once the test specimen was hand-pushed by the rail mechanism, a scaling movement was simulated.

Table 1. Descriptive characteristic variables for average surface roughness Sa (in μm) according to the used instrument and applied contact pressure (200 g/ 150 g; two $2 \times 2\text{-mm}$ test fields on each abutment)

Parameters	N	Surface Roughness MV \pm SD	Surface Roughness Min/Max
Pressure = 200 g	12	1.76 ± 2.09	0.60 - 6.03
Pressure = 150 g	12	1.23 ± 1.14	0.60 - 4.22
Acrylic Scaler Instrumentation (AS)	6	0.64 ± 0.04	0.60 - 0.69
Titanium Curette Instrumentation (TC)	6	0.65 ± 0.04	0.61 - 0.71
Ultrasonic Scaler Instrumentation (US)	6	$4.00 \pm 1.68^*$	2.28 - 6.03
Control/ No Instrumentation (C)	6	0.70 ± 0.05	0.63 - 0.78

Number of test variables (N), mean value (MV), standard deviation (SD), and minimum/maximum (Min/Max) are indicated. Instrumentation with ultrasonic scaler led to a significant increase of Sa-values

Symbol * indicates statistical significance of $P < .05$

Table 2. Descriptive characteristic variables for the developed interfacial area ratio (Sdr, %) according to the used instrument and applied contact pressure (200 g/ 150 g; two $2 \times 2\text{-mm}$ test fields on each abutment)

Parameters	N	Surface Roughness MV \pm SD	Surface Roughness Min/Max
Pressure = 200 g	12	0.73 ± 0.24	0.33 - 1.07
Pressure = 150 g	12	0.61 ± 0.18	0.28 - 0.85
Acrylic Scaler Instrumentation (AS)	6	$0.79 \pm 0.10^*$	0.62 - 0.92
Titanium Curette Instrumentation (TC)	6	$0.46 \pm 0.11^*$	0.28 - 0.60
Ultrasonic Scaler Instrumentation (US)	6	$0.57 \pm 0.23^*$	0.33 - 0.98
Control/ No Instrumentation (C)	6	$0.85 \pm 0.14^*$	0.64 - 1.07

Number of test variables (N), mean value (MV), standard deviation (SD), and minimum/ maximum (Min/ Max) are indicated. Treatment group comparison proved a statistically significant difference of Sdr-values for (AS) - (TC), (TC) - (C), and (US) - (C) (each: $P < .05^*$).

Table 3. Difference of average surface roughness (Sa, μm) after instrumentation with 200 g vs. 150 g contact pressure

Mann-Whitney U-Test						
	Pressure 200 g	Pressure 150 g	U	Valid N 200 g	Valid N 150 g	Exact p
Profile Sa (μm)	155.0000	145.0000	67.00000	12	12	0.798745

The variable contact pressure did yield no statistically significant difference on Sa-values for all instruments (Mann-Whitney-U-Test: $P = .8$)

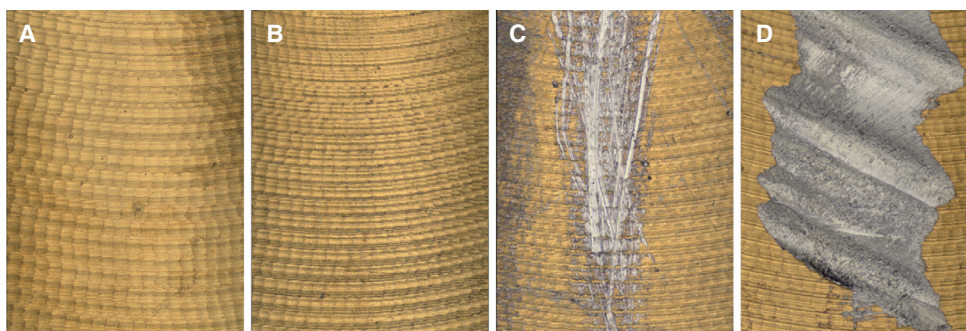


Fig. 3. Profilometric microscopy images of the titanium nitride (TiN) surfaces displayed differences depending upon the given treatment. Samples treated with 150 g contact pressure: Untreated TiN surface/ control (A), TiN surface instrumented with acrylic tip (B), titanium tip (C), and ultrasonic scaler (D). The acrylic scaler did not appear to affect the TiN surface after treatment. The severity of surface traces increased from utilizing titanium curettes to ultrasonic scalars. Ultrasonic scaling led to a significant increase of mean surface roughness (Sa) and patially detachment of the TiN-coating.

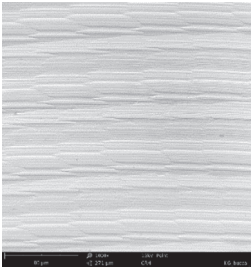
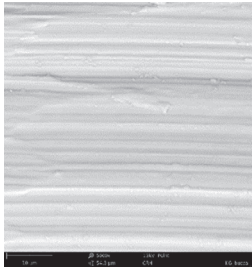
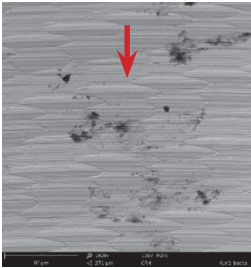
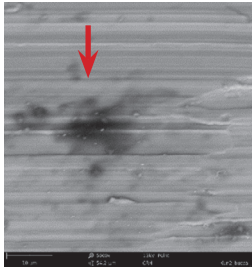

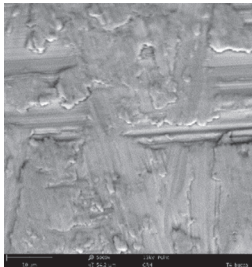
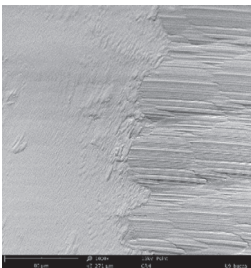
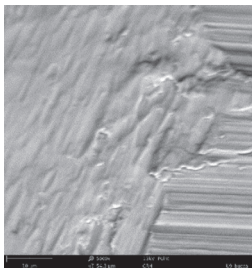
	SEM magnification 1000×	SEM magnification 5000×	Comment
Control group			
A: Untreated TiN-surface			CAM-milling grooves of intact TiN abutment surface visible
Test group: Applied instrument on TiN-surface with 150g pressure			
B: Acrylic scaler			Organic matter due to wear of friction of acrylic instrument
C: Titanium curette			Notable treatment traces
D: Ultrasonic scaler			Substantial substance removal of TiN-layer with planning effect

Fig. 4. SEM images of untreated titanium nitride surfaces (A: control) and instrumented titanium nitride surfaces (test). B: acrylic scaler, C: titanium curette, D: ultrasonic scaler.

resulting treatment traces on the abutmen's TiN-layer as pronounced. Ultrasonic treatment resulted in partial detachment of the TiN-coating in combination with a planning effect of the surface. Titanium curettes predominantly caused moderate treatment traces, while no traces or detectable substance removal have been determined after manipu-

lation with acrylic curettes. However, the samples displayed organic material on the abutment surface due to wear of friction of the acrylic instrument (Fig. 4). The difference between the treatment groups were statistically significant ($P < .001$)(Table 5). An influence of variable contact pressure with 200 g vs. 150 g was negligible ($P = .843$)(Table 6).

Table 4. Difference of developed interfacial area ratio (Sdr, %) after instrumentation with 200 g vs. 150 g contact pressure (all instruments)

Mann-Whitney U-Test						
	Pressure 200 g	Pressure 150 g	U	Valid N 200 g	Valid N 150 g	Exact p
Profile Sdr (%)	171.0000	129.0000	51.0000	12	12	0.241524

The variable contact pressure did yield no statistically significant difference on Sa-values for all instruments (Mann-Whitney-U-Test: $P = .8$)

Table 5. After instrumentation with ultrasonic scalers, all examiners classified the resulting treatment traces on the abutmen's TiN-layer as pronounced. Titanium curettes caused predominantly moderate treatment traces, while acrylic scalers did not appear to significantly affect the TiN-surface of the abutment

Istruments used	Classification of treatment traces			
	None	Moderate	Pronounced	Total
Acrylic Scaler (no. of test fields)	6	0	0	6
%	100.00%	0.00%	0.00%	
Titanium Curette (no. of test fields)	0	5	1	6
%	0.00%	83.33%	16.67%	
Ultrasonic Scaler (no. of test fields)	0	0	6	6
%	0.00%	0.00%	100.00%	
No. of Samples	6	5	7	18
	χ -Square	FG	P	
Pearson χ -Square	30.85714	FG = 4	$P = .00000^*$	

The difference between the treatment groups were statistically significant (Square-Test. $P < .001^*$)

Table 6. An influence of the applied contact pressure on the classification of treatment traces and detectable substance removal could not be demonstrated (Pearson-Square: $P = .843$)

Applied Pressure	Classification of treatment traces			
	None	Moderate	Pronounced	Total
200 g	3	2	4	9
%	33.33%	22.22%	44.44%	
150 g	3	3	3	9
%	33.33%	33.33%	33.33%	
No. of Samples	6	5	7	18
	χ -Square	FG	P	
Pearson χ -Square	0.3428572	FG = 2	$P = .84246$	

DISCUSSION

Since implant abutments are a part of the superstructure that is in direct contact with peri-implant tissues, their material and surface topography influence the soft-tissue reaction directly.³⁰ A titanium nitride (TiN) coating of CAD/CAM implant abutments may clinically offer esthetic and

biological advantages. Studies have shown a beneficial effect of TiN on antibacterial activity inhibiting the formation of microbial plaque and a prevention of compromising color differences of the peri-implant mucosa in patients with thin gingival biotypes.^{15,20,21} Although considered to be essential for the prevention of inflammatory peri-implant diseases, a periodic removal of debris from the implant abutment

shoulder could damage the TiN layer and change or roughen the surface profile. Surface alterations occurring over time might jeopardize the biocompatibility of the material and consequently lead to increased plaque accumulation that could adversely affect the peri-implant region.³¹ Within the limitations of this *in-vitro* investigation, the results demonstrate that titanium curettes and ultrasonic scalers with steel tips leave gradually pronounced treatment traces on TiN-coated CAD/CAM abutments, independent of the contact pressure applied (200 g vs. 150 g). While titanium curettes caused predominantly moderate treatment traces, ultrasonic scaling led to a partially detachment of the TiN-coating. In addition, manipulation with ultrasonic scalers resulted in a significant increase of average surface roughness (Sa) and developed interfacial surface area ratio (Sdr). No treatment traces, no alterations of roughness depth, and no detectable substance removal could be observed after manipulation with acrylic curettes. A concern, however, is the organic material located on the abutment surface due to frictional wear of the acrylic tip of the instrument. The biological consequences of implant or abutment contamination with plastic residues are critically discussed. It has been suggested that the biocompatibility of the surface may be impaired by the debris.³² Yang *et al.*³³ demonstrated a surface coverage of plastic remnants of up to 15% on titanium discs after instrumentation with various plastic instruments and subsequent attempt of cleaning with water spray or a chlorhexidine-soaked cotton pellets. There is a relative abundance of literature on the effect of mechanical instruments on titanium implants.^{31,34,35}; in contrast, the impact of scaling on the integrity of TiN coated abutments were not extensively studied so far. No *in vivo* studies on this topic have yet been published. Mengel *et al.*²⁸ examined the treatment of uncoated and TiN coated abutments *in vitro* with different instruments and summarized that a TiN coating may offer a way to prevent titanium abutments from sustaining damage during scaling. Moreover, the aforementioned trial concluded that, unlike the current study, TiN coated abutments can be treated with all instruments and equipment at low contact pressure without surface damage. Only high contact pressure on steel or titanium curettes and ultrasonic scalers with steel tips left pronounced treatment traces and caused a detachment of the surface coating.

While roughening of transmucosal prosthetic components should be avoided, it has not been adequately clarified to what extent various types of instrumentation alter the surface of the abutment shoulder and influence bacterial colonization. Similar to our results, Schmidt *et al.*³⁵ demonstrated an increase of average surface roughness using metal curettes at implant collars. However, no significant differences in surface roughness and biofilm formation based on one-time instrumentation have been observed with ultrasonic devices with steel or plastic coated tips. A single roughness parameter has only limited validity with regard to the surface texture. The Sa value as arithmetic mean possibly represents the most important parameter for assessment. To obtain a more detailed overview of the surface

characteristics, however, inclusion of the area excess (Sdr) appears to be useful. Sdr further differentiates surfaces of similar amplitudes and average roughness. To simulate the clinical situation as close as possible, standardized conditions by means of a customized device have been applied for mechanical treatment with defined pressure of 20 strokes. A comparison of the results to previous investigations proved to be difficult since pressure applied for treatment, application time of instruments, and number of strokes varied greatly among these studies.³¹

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions can be drawn: inappropriate instrument selection during regular recall and plaque control measures may have an adverse effect on the integrity of the TiN coating of CAD/CAM abutments. The resulting roughness could increase plaque and bacteria retention. To prevent resolution defects and/ or increased surface roughness at the transmucosal zone of TiN coated CAD/CAM abutments, only acrylic scaling instruments can be recommended for regular maintenance care.

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The authors declare that they have no conflict of interest. Dentsply Sirona Implants (Mölnal, Sweden) provided the CAD/CAM abutments for the experimental investigation. The design, documentation and analyses of this study were completed entirely independent of Dentsply Sirona Implants.

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