The Treatment of Uncoated and Titanium Nitride–Coated Abutments with Different Instruments

Reiner Mengel, DDS, Dr Med Dent, PhD[1]/Cordula Meer, DDS, Dr Med Dent[2]/
Lavin Flores-de-Jacoby, DDS, Dr Med Dent, PhD[2]

Purpose: *The aim of this in vitro study of titanium abutments was to investigate the extent of treatment traces, the roughness depth, and the quantity of titanium or, in the case of coated abutments, titanium nitride (TiN) removed from the surface after treatment with various instruments.* ***Materials and Methods:*** *Eleven uncoated, mechanically smoothed abutments and 11 TiN-coated abutments were used. The abutments were treated with titanium, steel, and plastic curettes; a rubber cup; an ultrasonic scaler with a steel tip; and an air scaler and cleaning powder. There were two 2 × 2-mm test fields on each abutment; each was subjected to standardized treatment with an instrument. The untreated surfaces of each abutment served as controls. The roughness depth (Rz) and profile height of treated and untreated surfaces were measured with a profilometer; profile height served as a basis for determining the amount of substance removed by treatment. The treatment traces were analyzed by scanning electron microscopy and light microscopy.* ***Results:*** *Both the ultrasonic scaler and the steel and titanium curettes left pronounced traces on the uncoated abutments and increased Rz. Substantial substance removal was recorded following the use of the ultrasonic scaler (17.57 ± 2.87 μm) and the steel curettes (8.48 ± 2.81 μm) on the uncoated abutments. In tests of the coated abutments, measurable substance removal (4.80 ± 0.99 μm) and increased roughness depth were noted only with use of the steel curettes. The treatment traces left by the other instruments were distinctly less pronounced than on the uncoated abutments. Light microscopy revealed detachment of the TiN coating after use of the ultrasonic scaler, titanium curettes, and steel curettes. Slight to moderate treatment traces were recorded after use of the rubber cup; no substance removal was observed. On the TiN-coated abutments, only slight treatment traces, if any, were recorded, and there was no substance removal. A planing effect (ie, an Rz decrease of 66.4%) was observed. The plastic curette and the air scaler caused no damage to the titanium or TiN surfaces.* ***Discussion and Conclusion:*** *The TiN-coated abutments displayed fewer treatment traces, less roughness depth, and less substance removal after being treated with various instruments. Two concerns, however, are the detachment of the coating after only few actions with steel and titanium curettes or with an ultrasonic scaler with steel tip, and the greater initial roughness depth of coated implants.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:232–238

Key words: *dental abutments, implant surface, profilometry, scanning electron microscopy, surface properties, titanium nitride*

Interaction between the osseointegrated implant and the oral environment entails the maintenance of an effective biologic margin in the peri-implant region. A lack of epithelial attachment around the implant results in bacterial penetration into the peri-implant tissue, giving rise to mucositis and peri-implantitis.[1–3] Consistent plaque control is therefore essential for the prevention of inflammatory peri-implant disease. Manual instruments, mechanical rotary or oscillating instruments, ultrasonic scalers, and particularly air scalers, have been effective for removal of plaque.[4,5] However, not all of these instruments are suitable for removing plaque from implants or abutments. In particular,

[1]Associate Professor, School of Dental Medicine, Department of Periodontology, Marburg University, Marburg, Germany.
[2]Professor, School of Dental Medicine, Department of Periodontology, Marburg University, Marburg, Germany.

Correspondence to: Dr Reiner Mengel, School of Dental Medicine, Department of Periodontology, Georg-Voigt-Str. 3, D-35033 Marburg, Germany. Fax: + 49 6421 2863270. E-mail: mengel@mailer.uni-marburg.de

treatment with steel curettes and ultrasonic scalers with steel tips causes sustained damage to the implant surface.[6–13] The resulting roughness on the surfaces of implants and abutments increases plaque retention.[14–16]

To make abutments more resistant to cleaning instruments in the present study, their surfaces were coated with titanium nitride (TiN). The aim of this in vitro study of titanium abutments was to investigate the extent of treatment traces, the roughness depth (Rz), and the quantity of titanium or TiN removed from the surface after treatment with various instruments. Uncoated, mechanically smoothed abutments and TiN-coated abutments were used.

Fig 1 Device used to ensure the reproducibility of the experiments.

MATERIALS AND METHODS

Twenty-two uncoated, mechanically smoothed 3i titanium abutments (Implant Innovations, West Palm Beach, FL) were obtained. To enhance their resistance to cleaning instruments, 11 of the abutments were coated with TiN using the cathodic arc vapor deposition technique. In this technique, individual atoms are deposited on a substrate under vacuum conditions. TiN is formed when ionized titanium atoms meet an ionized nitrogen atom on the substrate surface. The TiN layer has a golden color, a thickness of 1 to 5 µm, a density of 5.22 g/cm^3, and a melting point of 2,930°C. At a microhardness of 3,000 kg/mm, the equivalent of 85 on the Rockwell C scale,[17] the TiN layer is harder than carbide or hardened chromium.

The following instruments were used:

- A titanium curette (Deppeler, Rolle, Switzerland)
- A steel curette (Hu-Friedy, Chicago, IL)
- A plastic curette (Nobel Biocare, Göteborg, Sweden)
- A rubber cup with Zircate Prophy paste (Dentsply, York, PA)
- An ultrasonic scaler (Sonicflex) with steel tips (KaVo, Biberach, Germany)
- An air scaler (Prophyflex) with cleaning powder (KaVo)

The instruments and equipment were used as recommended by their manufacturers. Five scaling motions were performed with each of the three different curettes; the rubber cup was used for 20 seconds at 5,000 rpm. Instrumentation with the curettes and the rubber cup was performed with contact pressures of 0.4 N and 4 N. The ultrasonic scaler was used at 30,000 Hz with contact pressures of 1 N and 2 N for 20 seconds. The air scaler was used from a distance of 2 to 3 mm for 20 seconds at a pressure of 3,000 hPa.

For treatment purposes, the curettes, the ultrasonic scaler, and the rubber cup were firmly clamped in a mechanical arm balanced with weights (Fig 1). The air scaler was firmly clamped in the mechanical arm without any balance, 2 to 3 mm away from the treated surface. The abutments were fixed in a screw-type device on a slide that could be moved horizontally. This apparatus guaranteed standardized handling because of the exact orientation of the working direction of the instrument.

There were two 2 × 2-mm test fields on each abutment; each was treated with an instrument. For control purposes, an untreated surface in the immediate vicinity (a control field) was examined in each case. Using a mechanical profilometer (Perthometer S8P; Feinpruf Perthen, Göttingen, Germany), the Rz and profile height (Pt) of each were measured 4 times. The profilometer operated with an inductive sensor with a fine diamond tip. In this scanning procedure, a 3-dimensional surface was converted into a 2-dimensional profile section. The surface scanner was drawn by a precision feed unit in selectable scanning increments and at constant scanning speeds over the surface to be marked. The scanned surface profile was converted directly into electrical voltage proportional in size and polarity. The analog measuring signal was directed through a wave filter, evaluated in the computer circuit, and stored. The mean Rz was calculated according to Deutsches Institut für Normung (DIN) 4768, and the mean Pt was calculated according to DIN 4771. The Pt served as a basis for determining the amount of substance removed.

The test and control fields then were examined for treatment traces with a scanning electron microscope (CamScan4; CamScan, Cambridge, United Kingdom) and a light microscope (MBO50; Zeiss, Göttingen, Germany). The scanning electron microscope magnified the overall surface 300 times and the test and control fields 1,000 times. The quality of

Table 1 Treatment Traces and Roughness Depth and Profile Height of Treated and Control Surfaces

Surface/ instrument	Pressure	Control surface Mean Rz ± SD (μm)	Instrument surface Mean Rz ± SD (μm)	Substance removal Mean Pt ± SD (μm)	Treatment traces
Titanium					
Ultrasonic scaler	1.0 N	0.33 ± 0.09	1.10 ± 0.18	14.00 ± 3.31	Pronounced
	2.0 N	0.33 ± 0.09	1.45 ± 0.03	17.57 ± 2.87	Pronounced
Steel curette	0.4 N	0.24 ± 0.03	0.51 ± 0.06	1.84 ± 0.61	Pronounced
	4.0 N	0.38 ± 0.09	0.86 ± 0.06	8.48 ± 2.81	Pronounced
Titanium curette	0.4 N	0.38 ± 0.11	0.54 ± 0.05	0.00	Pronounced
	4.0 N	0.29 ± 0.06	0.61 ± 0.10	0.00	Pronounced
Rubber cup	0.4 N	0.52 ± 0.17	0.33 ± 0.05	0.00	Slight
	4.0 N	0.37 ± 0.05	0.40 ± 0.06	0.00	Moderate
Plastic curette	0.4 N	0.42 ± 0.01	0.50 ± 0.07	0.00	None
	4.0 N	0.35 ± 0.08	0.30 ± 0.08	0.00	None
Air scaler	3,000 hPa	0.35 ± 0.12	0.41 ± 0.09	0.00	None
Mean ± SD		0.38 ± 0.07	0.48 ± 0.17	1.15 ± 1.89	
Titanium nitride					
Ultrasonic scaler	1.0 N	1.27 ± 0.02	0.61 ± 0.14	0.00	Slight
	2.0 N	1.55 ± 0.14	0.73 ± 0.04	0.00	Moderate
Steel curette	0.4 N	1.55 ± 0.14	1.25 ± 0.10	0.00	None
	4.0 N	1.27 ± 0.02	2.32 ± 0.19	4.80 ± 0.99	Pronounced
Titanium curette	0.4 N	0.79 ± 0.25	0.58 ± 0.03	0.00	Moderate
	4.0 N	0.66 + 0.08	0.68 ± 0.10	0.00	Moderate
Rubber cup	0.4 N	0.80 ± 0.08	0.53 ± 0.01	0.00	None
	4.0 N	1.24 ± 0.21	0.42 ± 0.08	0.00	Slight
Plastic curette	0.4 N	0.68 ± 0.11	0.78 ± 0.21	0.00	None
	4.0 N	0.89 ± 0.07	0.55 ± 0.11	0.00	None
Air scaler	3,000 hPa	0.50 ± 0.13	0.73 ± 0.35	0.00	None
Mean ± SD		1.02 ± 0.37	0.87 ± 0.59	0.44 ± 0.90	

Rz = mean of the individual roughness depths of 5 successive individually measured distances; Pt = all profile deviations from the linear compensations; SD = standard deviation.

the treatment traces on the treated surfaces was classified by 2 independent investigators who, prior to study initiation, were calibrated for intra- and interexaminer reproducibility using duplicate measurements of a minimum of 50 treated surfaces. These investigators classified the treatment traces using 4 grades: none, slight, moderate, and pronounced. The untreated surfaces served as controls.

Statistical analysis was performed with SPSS statistical software (Chicago, IL). The means and standard deviations of the individual values registered for the different instruments were calculated. The Scheffé test was used for paired comparison of the instruments. The dependent variable was the mean of the difference between the mean Rz of the treated surface and the mean Rz of the control surface. In addition, the influence of the abutment surface, instruments, and contact pressure was investigated using a 3-factorial analysis of variance. Significance was set at $P < .05$.

RESULTS

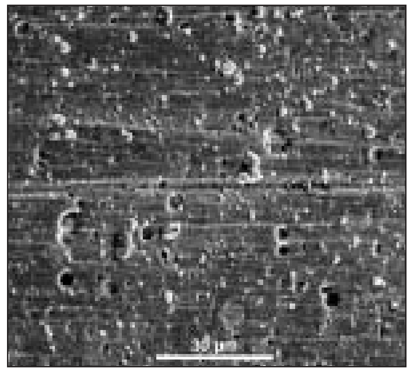
The coating gave the TiN-coated abutments greater initial roughness depth than the uncoated abutments (1.02 ± 0.37 μm vs 0.38 ± 0.07 μm) (Table 1, Figs 2a and 2b).

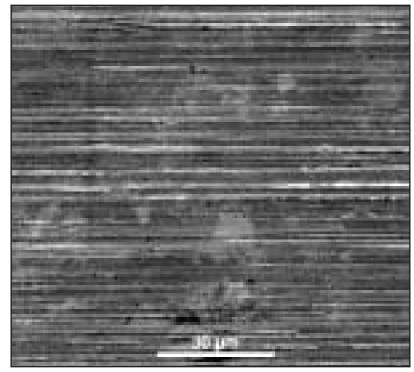
With a high contact pressure (≥ 2 N), the ultrasonic scaler, the steel curette, and the titanium curette left moderate to pronounced treatment traces on both coated and uncoated surfaces (Table 1, Figs 3a to 3c and 4a to 4c). Use of these 3 instruments at high pressure also increased the Rz of the uncoated surfaces (Table 1). Used with the lower contact pressure, these 3 instruments left notably fewer traces on the coated than on the uncoated abutments.

Substantial substance removal was recorded on the uncoated surfaces only after instrumentation with the steel curette at 4 N (8.48 ± 2.81 μm) and with the ultrasonic scaler at 2 N (17.57 ± 2.87 μm) (Table 1).

Fig 2a *(Left)* Untreated TiN-coated abutment, showing minute spherical particles on the untreated surface (original magnification ×1,000).

Fig 2b *(Right)* Untreated, uncoated abutment. Note the slight scoring (original magnification ×1,000).





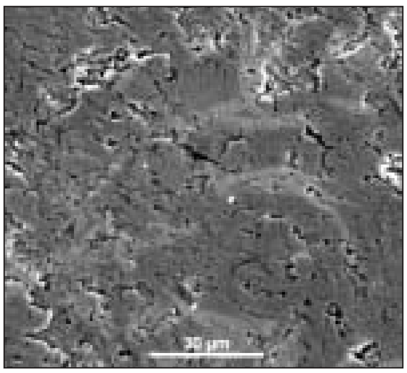


Fig 3a Ultrasonic scaler (2 N) on uncoated abutment. Pronounced treatment traces (original magnification ×1,000).

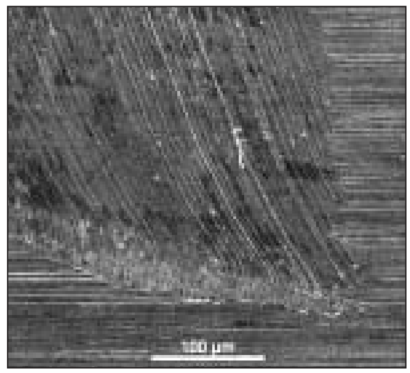


Fig 3b Steel curette (4 N) on uncoated surface. Pronounced treatment traces (original magnification ×300).

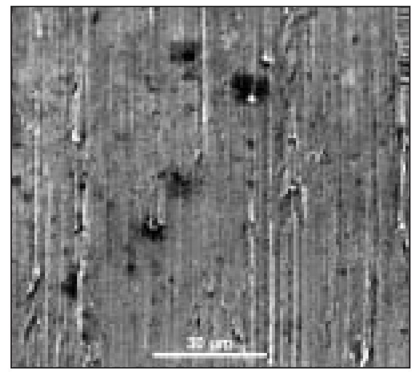


Fig 3c Titanium curette (4 N) on uncoated abutment. Pronounced treatment traces (original magnification ×1,000).

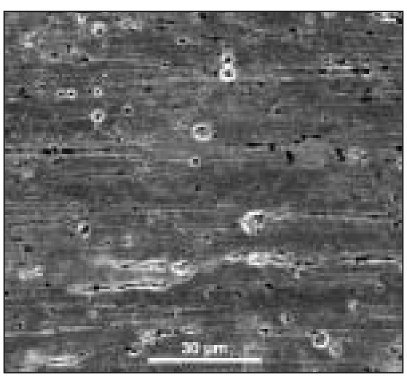


Fig 4a Ultrasonic scaler (2 N) on TiN-coated abutment. Moderate treatment traces (original magnification ×1,000).

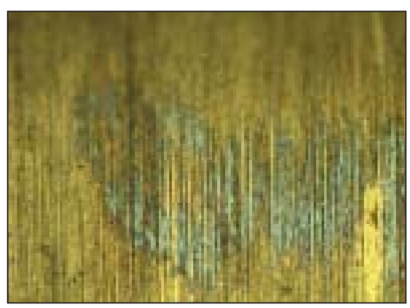


Fig 4b Ultrasonic scaler (2 N) on TiN-coated abutment. Partial detachment of the TiN coating (original magnification ×200, light microscopy).

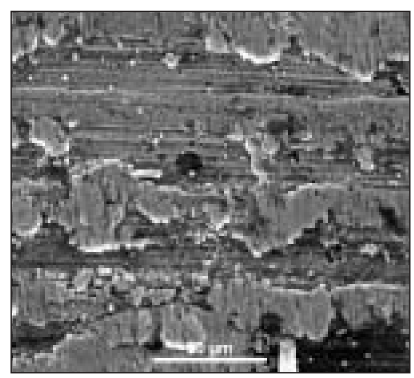


Fig 4c Titanium curette (4 N) on TiN-coated surface. Pronounced treatment traces (original magnification ×1,000).

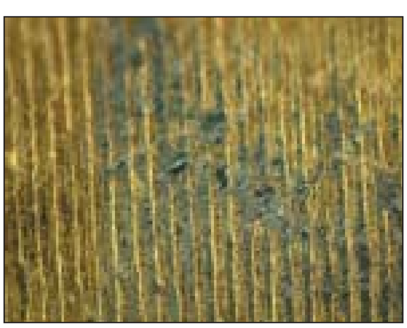


Fig 4d Titanium curette (4 N) on TiN-coated abutment. Partial detachment of the TiN coating (original magnification ×200, light microscopy).

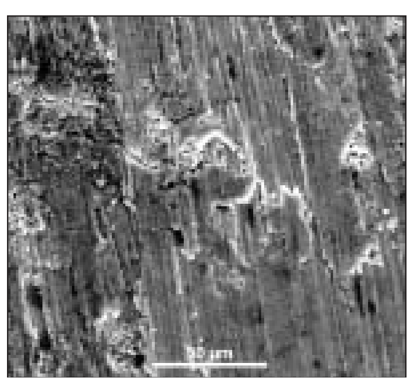


Fig 4e Steel curette (4 N) on TiN-coated surface. Pronounced treatment traces (original magnification ×1,000).

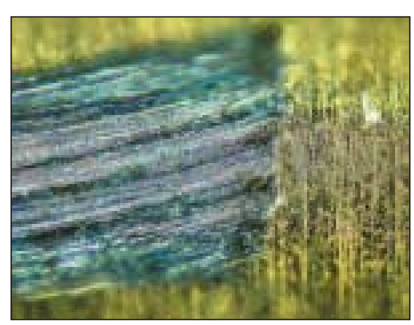


Fig 4f Steel curette (4 N) on TiN-coated abutment. Complete detachment of the TiN coating (original magnification ×200, light microscopy).

Table 2 Comparison of Individual Instruments Using Scheffé Test

	Steel curette	Titanium curette	Rubber cup	Plastic curette	Air scaler
Ultrasonic scaler	0.049*	0.997	0.000***	0.572	1.000
Steel curette		0.148	0.000***	0.000	0.312
Titanium curette			0.000***	0.292	1.000
Rubber cup				0.069	0.002**
Plastic curette					0.565
Air scaler					

*Significant ($P < .05$).
**Very significant ($P < .01$).
***Highly significant ($P < .001$).

Table 3 Significance of Test Parameters

Parameter	No. of observations	Mean ± SD	*P*
Material			.000***
Titanium	33	0.3027 ± 0.40322	
Titanium nitride	33	–0.1830 ± 0.55609	
Instrument			.000***
Ultrasonic scaler	12	0.1025 ± 0.90315	
Steel curette	12	0.3758 ± 0.51847	
Titanium curette	12	0.1458 ± 0.34734	
Rubber cup	12	–0.3125 ± 0.35126	
Plastic curette	12	–0.5170 ± 0.24071	
Air scaler	6	0.1383 ± 0.34126	
Pressure			.004**
Low	30	–0.0240 ± 0.40707	
High	30	0.1280 ± 0.67510	
Air scaler	6	0.1383 ± 0.34126	

**Very significant ($P < .01$).
***Highly significant ($P < .001$).

No substance removal was observed for coated abutments after treatment with the ultrasonic scaler. The Rz decreased from 1.55 ± 0.14 µm to 0.73 ± 0.04 µm (Table 1). Light microscopy revealed that the TiN coating was partially detached after treatment with the ultrasonic scaler (Fig 4d).

A similar result was recorded for coated abutments treated with the titanium curette. Although no substance removal was detectable, light microscopy revealed that the TiN coating was partially detached in the working direction of the curette (Fig 4e). Instrumentation of the coated abutments with the steel curette (4 N) resulted in marked substance removal (4.80 ± 0.99 µm) and an increased Rz (from 1.27 ± 0.02 µm to 2.32 ± 0.19 µm) (Table 1). Light microscopy revealed a total loss of the coating in the treated area (Fig 4f).

The rubber cup caused slight to moderate treatment traces on the uncoated abutments, and only slight traces, if any, on the coated abutments (Table 1). The clear-cut decrease in Rz of coated implants, from 1.24 ± 0.21 µm to 0.42 ± 0.08 µm, indicates that the rubber cup had a planing effect. The plastic curette and the air scaler caused no damage to the titanium or TiN-coated surfaces.

The results of the statistical analysis show that the abutment surface, the instrument, and the contact pressure applied each had either a highly significant ($P < .001$) or a very significant ($P < .01$) influence on the outcome (Tables 2 and 3). In comparison with the uncoated surfaces, the TiN-coated surfaces displayed a negative mean value of the differences between the mean Rz value of the instrumented surface and the mean Rz value of the control surface (–0.1830).

The paired comparison of individual instruments revealed a highly significant difference in the results after application of a rubber cup in comparison with those recorded for other instruments (Table 3). The results of ultrasonic scaler and steel curette application also differed significantly ($P < .05$).

DISCUSSION

Because of their physical characteristics, titanium abutments seem to accumulate more plaque than natural teeth.[14–16,18] Quirynen and colleagues reported that a rough surface could harbor 25 times as much bacteria as a smooth surface.[14] In addition, defects in the titanium surface may result in irreparable damage of the oxide layer, encouraging corrosion. This prevents the attachment of fibroblasts and jeopardizes the biocompatibility of the material.[19]

These findings lead to the demand for instruments or equipment for the removal of plaque and calculus from implants and abutments that can be used without causing surface damage. Various authors have investigated the effect of cleaning instruments on implant or abutment surfaces. Clear-cut treatment traces and substance removal were recorded on these surfaces following the use of steel curettes[6–12] and ultrasonic scalers with steel tips.[9,12,13] Although the use of Teflon-coated tips improved the results achieved with the air scaler and the ultrasonic scaler, these tips too must be used only with light contact pressure.[12] The same applies to the use of titanium curettes, which also leave slight traces on the surfaces.[9,10,13,19] Virtually no treatment traces are left by plastic curettes,[6–12,19] air scalers,[7–10,13,20] or rubber cups.[7–11,13]

TiN coating may offer a way to prevent titanium implants and abutments from sustaining damage during scaling. As the TiN coating adapts uniformly to the surface, surface-specific structures remain undistorted. The resulting metallurgic composite prevents splintering or detachment of the coating, even if the object is bent. Acids, alkalis, salts, and solutions have no detrimental effect on the coating. TiN is nontoxic, biologically inert, and resistant to corrosion.

This is the first study to publish in vitro results on the surface characteristics of TiN-coated dental implants or abutments; no in vivo studies on this topic have yet been published. It is unclear whether surface hardening for increased resistance to cleaning instruments is feasible in the long term. Promising results were reported in a study by Krämer and Lange[21] in which steel curettes were coated with TiN. In comparison with conventional, uncoated steel curettes, the coated curettes recorded markedly lower wear values. This advantage was lost, however, after repeated grinding of the curettes with a consequent loss of the TiN coating. Moreover, the coated curettes had distinctly rougher surfaces, a finding confirmed in the present study, as minute spherical particles were detected on the untreated control surfaces of the TiN-coated abutments.

Studies on retrieved TiN-coated hip implants and prosthetic femoral heads displayed a weakening of the coating adhesion, which was expressed in TiN fragments and metallic particles being released as a result of corrosion and wear.[22,23]

The results of the present in vitro study show that, unlike titanium-surfaced abutments, TiN-coated abutments can be treated with all instruments and equipment at low contact pressure without surface damage. However, steel or titanium curettes and ultrasonic scalers with steel tips used at a high contact pressure leave pronounced treatment traces and cause detachment of the surface coating.

As a limitation of the study design selected, it should be noted that this in vitro study deals with the effect of a single application of instruments on abutments. The effect of repeated applications within the scope of regular professional plaque control remains a matter of speculation.

CONCLUSIONS

In summary, it can be stated that the TiN-coated abutments displayed fewer treatment traces, a lower roughness depth, and less substance removal than the uncoated abutments after a single treatment with various instruments. Two concerns, however, are the detachment of the coating after only few actions with steel and titanium curettes or with an ultrasonic scaler with steel tip, and the greater initial roughness depth induced by the coating.

REFERENCES

1. Berglundh T, Lindhe J, Marinello C, Ericsson I, Liljenberg B. Soft tissue reactions to de novo plaque formation on implants and teeth. An experimental study in the dog. Clin Oral Implants Res 1992;3:1–8.
2. Ericsson I, Berglundh T, Marinello C, Liljenberg B, Lindhe J. Long-standing plaque and gingivitis at implants and teeth in the dog. Clin Oral Implants Res 1992;3:99–103.
3. Leonhardt A, Berglundh T, Ericsson I, Dahlen G. Putative periodontal pathogens on titanium implants and teeth in experimental gingivitis and periodontitis in beagle dogs. Clin Oral Implants Res 1992;3:112–119.
4. Mengel R, Buns C, Stelzel M, Flores-de-Jacoby L. An in vitro study of oscillating instruments for root planing. J Clin Periodontol 1994;21:513–518.
5. Mengel R, Stelzel M, Flores-de-Jacoby L. An in vitro study of various instruments for root planing. Int J Periodontics Restorative Dent 1997;17:592–599.
6. Fox SC, Moriarty JD, Kusy RP. The effects of scaling a titanium surface with metal and plastic instruments: An in vitro study. J Periodontol 1990;61:485–490.
7. Gantes BG, Nilveus R. The effects of different hygiene instruments on titanium surfaces: SEM observations. Int J Periodontics Restorative Dent 1991;11:225–239.

8. Homiak AW, Cook PA, DeBoer J. Effect of hygiene instrumentation on titanium abutments: A scanning electron microscopy study. J Prosthet Dent 1992;67:364–369.
9. Meschenmoser A, d'Hoedt B, Meyle J, et al. Effects of various hygiene procedures on the surface characteristics of titanium abutments. J Periodontol 1996;67:229–235.
10. Mengel R, Buns C, Vidahl T, Flores-de-Jacoby L. An in vitro study of the treatment of implant surfaces with different instruments. Int J Oral Maxillofac Implants 1998;13:91–96.
11. Rapley JW, Swan RH, Hallmon WW, Mills MP. The surface characteristics produced by various oral hygiene instruments and materials on titanium implant abutments. Int J Oral Maxillofac Implants 1990;5:47–52.
12. Rühling A, Kocher T, Kreusch J, Plagman HC. Treatment of subgingival implant surfaces with Teflon-coated sonic and ultrasonic scaler tips and various implant curettes. Clin Oral Implants Res 1994;5:19–29.
13. Thomson-Neal DM, Evans GH, Meffert RM. Effects of various prophylactic treatments on titanium sapphire and hydroxylapatite-coated implants: An SEM study. Int J Periodontics Restorative Dent 1989;9:301–311.
14. Quirynen M, van der Mei C, Bollen CML, et al. An in vivo study of the influence of the surface roughness of implants on the microbiology of supra- and subgingival plaque. J Dent Res 1993;72:1304–1309.
15. Quirynen M, van der Mei C, Bollen CML, et al. The influence of surface-free energy on supragingival plaque microbiology. An in vivo study on implants. J Periodontol 1994;65:162–167.
16. Quirynen M, Bollen CML, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: Short-term observations. Int J Oral Maxillofac Implants 1996;11:169–178.
17. International Oraganization for Standardization. Metallic Materials—Rockwell Hardness Test/Scales A-B-C-D-E-F-G-H-K (ISO 6508-1986). Geneva, Switzerland: Author, 1986.
18. Quirynen M, Bollen CML. The influence of surface roughness and surface-free energy on supra- and subgingival plaque formation in man. A review of the literature. J Clin Periodontol 1995;22:1–14.
19. Dmytryk JJ, Fox SC, Moriarty JD. The effects of scaling titanium implant surfaces with metal and plastic instruments on cell attachment. J Periodontol 1990;61:491–496.
20. Parham PL Jr, Cobb CM, French AA, Love JW, Drisko CL, Killoy WJ. Effects of an air-powder abrasive system on plasma-sprayed titanium implant surfaces: An in vitro evaluation. J Oral Implantol 1989;15:76–86.
21. Krämer W, Lange DE. Qualitätsbeurteilung von Küretten verschiedener Hersteller in bezug auf ihre Standzeit. Quintessenz 1990;10:1–12.
22. Harman MK, Banks SA, Hodge WA. Wear analysis of a retrieved hip implant with titanium nitride coating. J Arthroplasty 1997;12:938–945.
23. Raimondi MT, Pietrabissa R. The in vivo wear performance of prosthetic femoral heads with titanium nitride coating. Biomaterials 2000;21:907–913.