Effect of Different Surface Treatments on Retention of Cement-Retained, Implant-Supported Crowns

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Purpose: To evaluate the effect of different treatments applied to titanium implant abutment surfaces on the retention of implant-supported crowns retained using resin cement. ***Materials and Methods:*** A total of 72 titanium implant abutments were divided into six groups (n = 12 each) based on the selected surface treatment: *(1)* untreated; *(2)* sandblasted; *(3)* hydrogen peroxide–etched; *(4)* atmospheric plasma; *(5)* chemical mechanical polishing; and *(6)* titanium dioxide nanocoating. After the surface treatments, scanning electron microscopy analyses and roughness measurements of the abutment surfaces were performed. Then, 72 metal copings were fabricated and cemented onto the abutments with dual-curing resin cement. After the thermocycling process, crown retention was measured by using a universal testing machine. The experimental results were statistically evaluated with one-way analysis of variance, Tukey honest significant difference, and Tamhane T2 tests. ***Results:*** The highest surface roughness values were obtained in the sandblasted group (1.44 um), which also showed in the highest retention values (828.5 N), followed by the hydrogen peroxide etching group (490.7 N), the atmospheric plasma group (466.5 N), the chemical mechanical polishing group (410.8 N), and the control group (382.6 N). ***Conclusion:*** Sandblasting, hydrogen peroxide, etching, and atmospheric plasma treatments significantly increased crown retention, and all alternative treatments, with the exception of TiO_2 nanocoating, worked better than the control samples. *Int J Prosthodont 2023;36:49–58. doi: 10.11607/ijp.6602*

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Titanium has been used successfully as a dental implant material as it is biocompatible, resistant to corrosion due to the formation of a stable oxide layer, and has excellent mechanical properties.[1] Titanium dioxide (TiO_2), which forms on the titanium surface during surface treatment, is a continuous, nonporous, and adhesive oxide film layer that is protective and resistant to corrosion.[2] Titanium surface treatments aim to eliminate the weak layers of bare titanium that negatively affect bond strength and to form an adhesive layer that promotes bonding.[3] There are various surface treatments that are used to enhance surface adhesion behavior, such as:

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Fig 1 Implant analog with abutment seated in an acrylic resin block.

- Sandblasting: The most common, inexpensive, and easiest method.[4]
- Hydrogen peroxide etching: It has been demonstrated in the literature that high hydrogen peroxide (H_2O_2) concentrations increase the corrosion rate of titanium-based samples.[5] Increased corrosion rates result in increased surface roughness, and it is known that surface roughness directly affects the attachment behavior of the surface. In addition, it has been reported that applying reactive oxygen to the titanium surface during H_2O_2 etching induces the release of titanium ions from the surface of the implant and induces Ti-O formation,[6–8] which increases surface hydrophilicity.[9] This is illustrated by the following chemical reaction:

$$Ti + OOH^{-} + 3OH^{-} \longleftarrow\!\!-\!\!-\!\!\longrightarrow Ti(OH)_2O_2 + H_2O + 4e^{-}$$

- Atmospheric plasma: It has been found that, with atmospheric plasma treatment, an oxide layer is formed on the titanium surface. The surface therefore becomes hydrophilic, and adhesion properties may be affected.[10]
- Chemical-mechanical polishing (CMP): CMP is a newly introduced technique for the surface structuring of bioimplants. It has been demonstrated that CMP treatment enables control of surface roughness from the nano- to the microlevel through the changing of properties of the pad material, down force, slurry particle sizes, and concentration in the CMP slurries.[11] In addition, H_2O_2 as the oxidizer during the CMP method forms a continuous Ti-O layer on the titanium implant surface.[12]
- TiO_2 nanocoating: Beyond mechanical surface treatment methods, chemical coating methods are a good alternative for increasing surface roughness to enhance the adhesion behavior of implant materials. It has been reported that a thin oxide film layer formed on titanium surfaces by TiO_2 nanocoating with the sol-gel method[13] can be used to increase the adhesion between dental ceramics and metal substructures.[14]

In the present study, sandblasting, H_2O_2 etching, atmospheric plasma, CMP, and TiO_2 nanocoating treatments were applied on dental implant abutment surfaces, and the effects of these treatments on the crown retention and the surface roughness and morphology of the treated abutments were evaluated. The null hypothesis was that no difference would exist in the retention of cement-retained, implant-supported crowns following different surface treatments.

MATERIALS AND METHODS

A total of 72 titanium implant abutments (Mode Medikal, 5-mm height) and 72 titanium implant analogs (Mode Medikal) were used. The implant analogs were embedded vertically into autopolymerized acrylic resin blocks (Meliodent) using a dental surveyor (Fig 1). The 72 abutments were divided into 6 groups, with 12 samples in each group, according to surface treatment technique:

1. Control group: No surface treatment applied other than original machining to shape the titanium.
2. Sandblasted group: Abutment surfaces were sandblasted with 110-µm aluminum oxide (Al_2O_3) particles (Mega Strahlkorund) at 2.5-bar pressure from a 10-mm distance for 10 seconds. After sandblasting, the samples were steam cleaned for 5 seconds and air dried for 10 seconds.
3. H_2O_2–etched group: A high-pH, oxidizer-based etching process was implemented by using 35 wt% H_2O_2. The etching process was applied by dipping into the high-concentration H_2O_2 solution (Sigma-Aldrich). The abutment samples were then dipped into the beakers containing 15 mL of concentrated H_2O_2 for 30 minutes at room temperature. H_2O_2–based etching is more suitable than acid-based etching because its long postoperation cleaning process decreases the risk of chemical residue; nevertheless, a postcleaning procedure by ultrasonic treatment in deionized water (DIW) was applied to the abutment samples after the etching steps.

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4. Atmospheric plasma group: The abutment surfaces received a plasma treatment with an atmospheric plasma torch (Plasmatreat), applied for 5 seconds and at 2-bar pressure, with an average jet power of 1 kVA and a processing speed of 5 mm/second at a distance of 5 mm from the abutment surface.
5. CMP group: CMP slurries were prepared by diluting commercial SiO_2 slurry (BASF) in a 5% weight final concentration. To provide stability, the suspensions were ultrasonicated at a pH of 9. H_2O_2 (Sigma Aldrich, 34.5% to 36.5% purity) was used as an oxidizer during the CMP experiments to create an oxide layer on top of the titanium implant. Abutment samples were polished in the CMP slurries in the presence of 3 wt% oxidizer for an additional 10 minutes. All samples were cleaned in an ultrasonic bath with acetone, then ethanol, and then pH-adjusted water for 5 minutes to ensure a clean surface.
6. TiO_2 nanocoating group: TiO_2 nanocoating was applied to increase attachment of the additional nonmetallic coating layer on the titanium to enable increased interactions between the metallic titanium and ceramic TiO_2 layer through the titanium ions. TiO_2 nanofilm was deposited using a sol-gel technique.[15,16] $TiOSO_4$ was used as a precursor, and 0.5-M Ti source was dissolved in 0.5M H_2O (DIW) and 20-M ethanol, mixed well under continuous stirring, and pH-adjusted with HNO_3 (0.1 M) at pH = 1.23. The Ti source underwent a thorough hydrolysis reaction as provided in the following equation[1]:

$$TiOSO_4(s) + 2H_2O\ (aq) \leftarrow\!\!-\!\!-\!\!\rightarrow 2H+(aq) + SO_4\text{-}(aq) + TiO(OH)_2(s)$$

The TiO_2–containing transparent solution was obtained as a product of the hydrolysis reaction. The abutment samples were dipped into the solution with a dip coater tool (PTL-MMB01, MTI) to deposit the TiO_2 nanofilm.[17] The abutments to be coated with the TiO_2 sol-gel were lowered into the coating solution and then withdrawn at a specific pull speed (140 mm/minute) and distance (100 mm). The samples were dried in air at 200°C for 1 hour by using the furnace integrated in the dip coating tool. All chemicals used in the experiment were obtained from Sigma-Aldrich.

After the surface treatments, one sample from the control and from each of the five different experimental groups were randomly chosen, and their abutment surfaces were examined under scanning electron microscopy (SEM; EVO LS 10, Zeiss) with ×1,000 magnification. Surface roughness measurements of the samples were conducted with a profilometer (SJ-400, Mitutoyo). Roughness values (Ra) were measured from three different sites that were randomly selected on all abutment surfaces, and the mean roughness values were calculated.

Fig 2 Implant analog with abutment and coping in an acrylic resin block.

After the surface treatments, abutments were attached to the implant analogs and torqued according to the directions provided by the manufacturer. Next, the abutment screw access holes were filled with cotton pellets and temporary filling material (Cavit, 3M ESPE). Abutment surfaces were scanned with a 3D scanner (Shining 3D), and the data were computerized. Crowns were designed with the Exocad Dental CAD program. A total of 72 copings were fabricated with a 2.2-mm internal diameter loop on the occlusal surface for attachment to the universal testing machine (Fig 2). To provide standardization of the fabrication of the metal copings, laser sintering technology (ProX 300, 3D Systems) and a cobalt-chromium alloy (ST2725G, SINT-TECH) were used.

A dual-curing resin cement (Panavia F 2.0, Kuraray) was used. The cement was mixed according to the manufacturer's instructions. A thin layer was placed in the metal copings, and the metal copings were placed on the abutments with finger pressure. After 10 seconds, excess cement was removed, and the samples were weighted for 10 minutes under 5-kg force. After cementation, samples were stored at 37°C in distilled water for 24 hours and thermocycled between 5°C and 55°C with 30-second dwell times for 5,000 cycles.

Retention values of the samples were measured at 0.5 mm/minute crosshead speed with a universal testing

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Table 1 One-way ANOVA Results for Mean Retention Values

	Sum of squares	df	Mean square	F	*P*
Between groups	1886650.842	5	377330.168	143.291	.000*
Within groups	173798.961	66	2633.318		
Total	2060449.803	71			

Table 2 One-way ANOVA Results for Mean Roughness Values

	Sum of squares	df	Mean square	F	*P*
Between groups	4.956	5	0.991	9.425	.000*
Within groups	6.941	66	0.105		
Total	11.897	71			

*Significant value ($P < .05$).

Table 3 Minimum, Maximum, and Mean ± SD Values for Surface Roughness (μm)

Groups	No. of specimens	Minimum	Maximum	Mean ± SD
Control	12	0.27	2.09	0.81 ± 0.5
Sandblasted	12	1.12	1.62	1.44 ± 0.2
H_2O_2 etching	12	0.31	1.2	0.76 ± 0.3
Atmospheric plasma	12	0.28	0.94	0.61 ± 0.2
CMP	12	0.31	1.34	0.88 ± 0.4
Sol-gel nanocoating with TiO_2	12	0.42	1.38	0.92 ± 0.3

machine (MIN-100, Esetron Smart Robotechnologies). Roughness and retention values of the samples were analyzed using one-way analysis of variance (ANOVA), Tukey honest significant difference test, and Tamhane T2 test. Significance was evaluated at the $P < .05$ level.

After the tensile test, the abutment surfaces were examined under a stereomicroscope (SZ61, Olympus Optical) at ×20 magnification, and images were analyzed with a software program. The failure mode was scored as either adhesive (no cement residue on the abutment surface) or cohesive (cement residue on both the abutment surface and crown inner surface).

RESULTS

The one-way ANOVA results provided in Tables 1 and 2 show that the surface treatments significantly affected the roughness and the retention values ($P < .05$).

Roughness Values

The control group showed an average roughness value of 0.8 ± 0.5 μm. The control group was the only group with high SD rates because of the machine processing. Machining techniques generally produce a surface with defects that contain grooves, ridges, and traces of the tool used for manufacturing. These random surface characteristics directly affect the surface roughness and result in higher deviation compared to controlled surface treatment methods.

Mean surface roughness values were found to be highest in the sandblasted group (1.4 ± 0.2 μm) and lowest in the atmospheric plasma group (0.6 ± 0.2 μm) (Table 3 and Fig 3). The surface roughness of the sandblasted group was found to be significantly higher than all other groups ($P < .05$). For the other groups, no statistically significant difference was observed in terms of roughness values ($P > .05$; Table 4).

SEM

There were distinctive irregularities and deep macrocavities on the abutment surface in the sandblasted group compared to the other groups. There were no differences in terms of surface morphology between the control group and the other groups (Fig 4).

Retention Values

The mean retention values were found to be highest in the sandblasted group (828.5 ± 57.0 N) and

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lowest in the TiO_2 nanocoating group (333.7 ± 45.3 N) (Table 5 and Fig 5).

The mean retention value calculated for the sandblasted group was significantly higher than the control group, as well as the other experimental groups (Fig 6; *P* < .05). Conversely, the mean retention value of the TiO_2 nanocoating group was significantly lower compared to all other groups except for the control group (*P* < .05). Statistical analyses showed that there was a significant difference between *(1)* the atmospheric plasma and the control groups; *(2)* the H_2O_2 and CMP groups; and *(3)* the H_2O_2 and the control groups (*P* < .05). Among the other groups, no statistically significant difference was observed in terms of the mean retention values (*P* > .05) (Table 6).

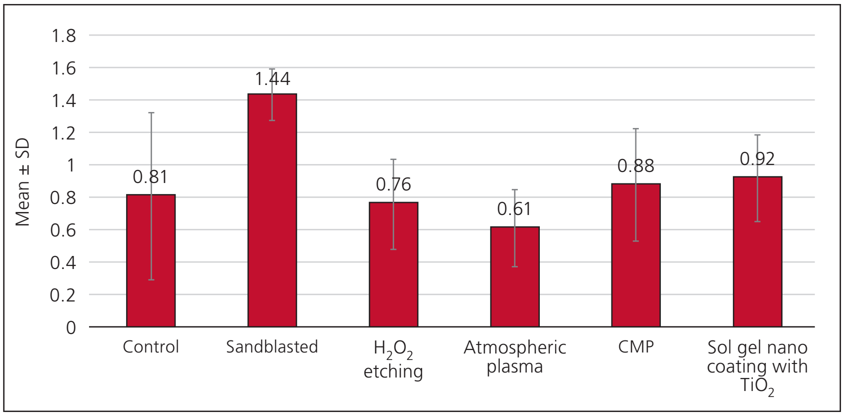

Fig 3 Mean ± SD surface roughness values.

Table 4 Post hoc Evaluation of Surface Roughness Values According to Tamhane T2 Test

		Surface roughness
		P
Control	Sandblasted	.022*
	H_2O_2 etching	1.000
	Atmospheric plasma	.982
	CMP	1.000
	Sol-gel nanocoating with TiO_2	1.000
Sandblasted	H_2O_2 etching	.000*
	Atmospheric plasma	.000*
	CMP	.002*
	Sol-gel nanocoating with TiO_2	.000*
H_2O_2 etching	Atmospheric plasma	.936
	CMP	.999
	Sol-gel nanocoating with TiO_2	.934
Atmospheric plasma	CMP	.455
	Sol-gel nanocoating with TiO_2	.095
CMP	Sol-gel nanocoating with TiO_2	1.000

*Significant value (*P* < .05).

Failure Modes

All of the samples in the sandblasted group showed cohesive failure (*P* < .05; Fig 7a). The control, H_2O_2 etching, atmospheric plasma, CMP, and TiO_2 nanocoating groups showed predominantly adhesive failure (*P* > .05; Table 7 and Fig 7b).

DISCUSSION

The present study evaluated the effect of different treatments applied to the surface of titanium abutments on the retention between the abutment and the crown. The study concluded that the retention values increased with all surface treatments except for the TiO_2 nanocoating group, which is the only group that resulted in a different surface film because of the chemical coating process.

The phosphate ester group in Panavia F 2.0 resin cement (Kuraray) is supposed to bond directly to the metal oxides on the surface of the implant.[18] In their studies, Fonseca et al,[19] Di Francescantonio et al,[20] and Ozcan and Valandro[21] reported that Panavia F 2.0 had the highest bond strength to a titanium surface when compared to other resin cements. Therefore, in the present study, Panavia F 2.0 resin cement was selected for all test groups.

The surface area of an alloy can be increased by obtaining a microretentive topography on the alloy surface through sandblasting, and a stronger bond is therefore achieved between the alloy and the cement.[22] In the present study, sandblasting resulted in significant increases in the surface roughness and retention values compared to the other groups (*P* < .05). These results are in agreement with the literature,[23–25] indicating that increased surface roughness provides more pronounced mechanical bonding between the abutment and the cement and is thus effective in increasing retention.

It is known that an H_2O_2 etching treatment increases the bond strength by forming oxidation on the titanium surface.[26] Nagassa et al[27] and Daw et al[28] applied H_2O_2 solutions at 30% concentrations to titanium disc surfaces

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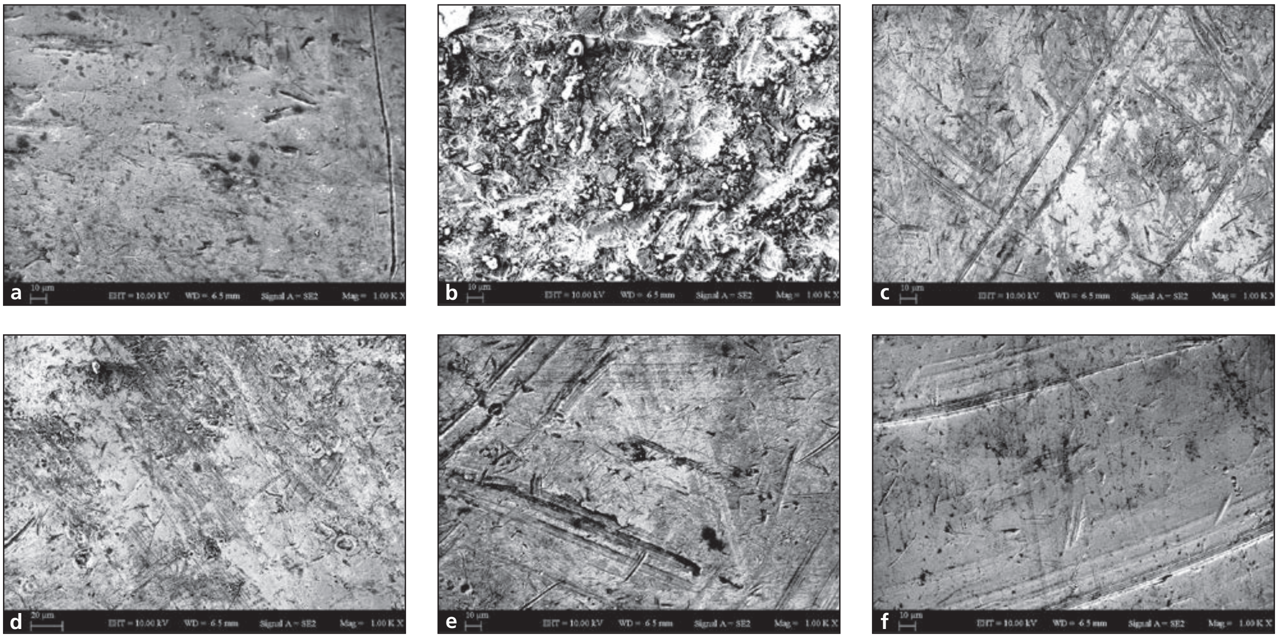

Fig 4 Scanning electron microscopy images (×1,000 magnification). *(a)* Control. *(b)* Sandblasted. *(c)* H_2O_2 etching. *(d)* Atmospheric plasma. *(e)* CMP. *(f)* Sol-gel nanocoating with TiO_2.

Table 5 Minimum, Maximum, and Mean ± SD Retention Values (N) for each Group

Groups	No. of specimens	Minimum	Maximum	Mean ± SD
Control	12	307.9	488.9	382.6 ± 48.4
Sandblasted	12	740.2	895.6	828.5 ± 57.0
H_2O_2 etching	12	412.3	572.8	490.7 ± 48.2
Atmospheric plasma	12	382.3	540.5	466.5 ± 54.3
CMP	12	340.9	493.4	410.8 ± 53.7
Sol-gel nanocoating with TiO_2	12	247.9	386.1	333.7 ± 45.3

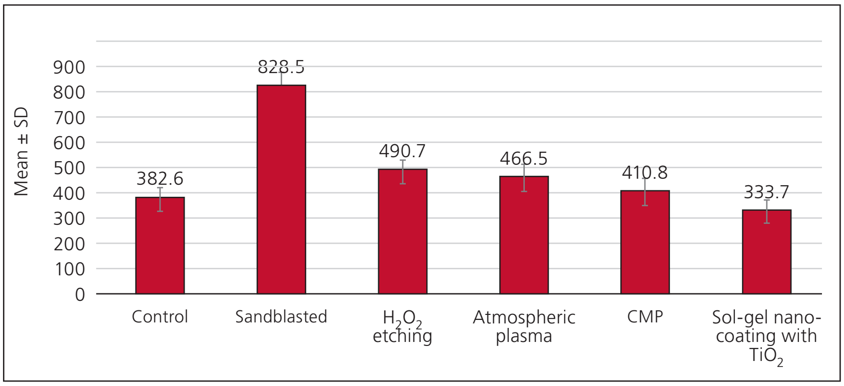

Fig 5 Mean ± SD retention values.

for different periods of time and reported that the surface roughness values increased as the time increased. Elsaka and Swain[29] applied 10% and 30% H_2O_2 to titanium surfaces for different periods of time and stated that, for these concentrations, the roughness values showed no significant difference from those of the control group; however, the bond strength at each concentration increased compared to the control group, with 30% H_2O_2 etching increasing the bond strength more than the 10% H_2O_2 concentration. In addition, Yoshida et al[30] reported that 34.5% H_2O_2 etching on titanium surfaces for different periods increased the bond strength. In the present study, 35% H_2O_2 etching was applied on the abutment surfaces for 30 minutes, and the H_2O_2 etching group showed the highest retention value after the sandblasted group.

Duske et al[31] reported that atmospheric plasma treatment is an efficient surface modification method that can change physicochemical properties, including hydrophobicity, and can develop the surface

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properties of the material; thus, it can be used for surface modifications of implant abutments. Seker et al[32] reported that atmospheric plasma treatment applied on a titanium disc surface increased roughness values significantly when compared to a control group; although the bond strength also increased, it was not significant. El-Helbawy et al[33] found that the surface roughness values of a group in which oxygen plasma treatment was applied to titanium abutment surfaces were similar to the control group. The authors also reported that oxygen plasma treatment significantly increased the retention between the abutment and crown compared to the control group. According to the present study, atmospheric plasma treatment significantly increased the retention value between the abutment and the crown compared to the control group ($P < .05$).

In the present study, there was no significant difference between the surface roughness values of the atmospheric plasma, H_2O_2 etching, and control groups ($P > .05$). However, the retention values of the atmospheric plasma and H_2O_2 etching groups were significantly higher than the control group ($P < .05$). Despite the low surface roughness, the present authors believe that the cement used provides a strong chemical bond when coupled with the surface treatments implemented on bare titanium and has an effect on increasing the retention value.

Similar to the present results, Kamijo et al[26] stated that when the titanium surface is immersed in H_2O_2, oxidation occurs on the surface, increasing the bond strength to the resin. Foest et al[34] indicated that plasma alters the surface energy and chemistry as a result of formation of high-concentration reactive species (O_2). They also reported that the surface-cleaning property of the plasma provided chemical bonding of the cement to the titanium surface.

Fig 6 Correlation between retention and roughness.

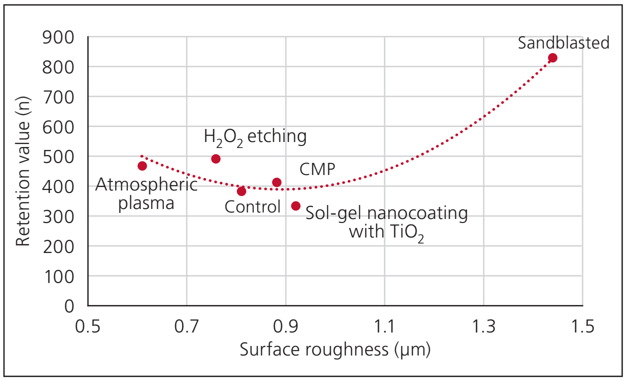

Table 6 Post hoc Evaluation of Retention Values (N) According to Tukey Honest Significant Difference Test

		P
Control	Sandblasted	.000*
	H_2O_2 etching	.000*
	Atmospheric plasma	.002*
	CMP	.759
	Sol-gel nanocoating with TiO_2	.194
Sandblasted	H_2O_2 etching	.000*
	Atmospheric plasma	.000*
	CMP	.000*
	Sol-gel nanocoating with TiO_2	.000*
H_2O_2 etching	Atmospheric plasma	.856
	CMP	.004*
	Sol-gel nanocoating with TiO_2	.000*
Atmospheric plasma	CMP	.097
	Sol-gel nanocoating with TiO_2	.000*
CMP	Sol-gel nanocoating with TiO_2	.006*

*Significant value ($P < .05$).

CMP treatment is used to increase the corrosion resistance and biocompatibility[35] of dental implant material.[2] It has been reported that during CMP treatment, when the top film surface of the titanium is exposed to chemicals in the polishing slurry (containing submicron particles and corrosives), a chemically altered top oxide film with a protective nature is formed.[35,36] Studies on CMP have generally focused on evaluating the effect of CMP on dental implant osseointegration. In the literature, no study has been found that evaluates the effect of CMP on retention between the abutment and the crown.

In the present study, CMP on the abutment surface was found to increase the retention value between the abutment and the crown, but this was not significant when compared to the control group ($P > .05$). However, since CMP treatment produces chemical and mechanical actions simultaneously, this dual effect can be further tuned to obtain the desired surface characteristic, including more pronounced roughness. It is also possible to

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Fig 7 *(a)* Cohesive and *(b)* adhesive failure between abutment and cement.

Table 7 Failure Modes in Each Group

Failure mode		Control	Sandblasted	H_2O_2 etching	Atmospheric plasma	CMP	Sol-gel nanocoating with TiO_2	Total
Adhesive	No.	7	0	7	9	7	7	37
	%	58.3	0	58.3	75	58.3	58.3	51.4
Cohesive	No.	5	12	5	3	5	5	35
	%	41.7	100	41.7	25	41.7	41.7	48.6

obtain a range of roughness values by using different abrasive particles and/or pad materials.[2] In other words, CMP is a combination of the mechanical action that is similar to the sandblasting process and the chemical action that is similar to the H_2O_2 etching. Therefore, the nature of CMP treatment allows for tuning abilities that go beyond the simple approach used for the experiment in this study. In addition, higher roughness and retention values can be obtained by more aggressive abrasive particles/pad materials, as well as by increasing the concentration of H_2O_2 as an oxidizer. Further studies should therefore be conducted.

TiO_2 nanocoating with sol-gel can be used to form thin metal oxides on titanium surfaces.[13] It is reported that oxide coatings can be used to increase adhesion between dental ceramics and metal infrastructures.[14] Advincula et al[37] and Krzak-Roś et al[38] reported that TiO_2 nanocoating with sol-gel on a titanium surface increased the surface roughness. Bieniaś et al[14] reported that SiO_2 and SiO_2–TiO_2 coatings using the sol-gel method are simple and effective treatments that can be applied in the clinic to increase the bond strength between titanium and porcelain. In the present study, the TiO_2 sol-gel nanocoating resulted in the lowest retention value, although the surface roughness value was higher than the control group ($P > .05$).

There are studies in the literature indicating that, after various surface treatments and despite high surface roughness values, bond strength was low.[39–41] Lim et al[39] and Darvell et al[40] reported that surface roughness may increase the stress between the metal and cement, cause voids between the metal and cement, and prevent complete wetting.

The adhesion of cement to the surface depends on micromechanical adhesion and physicochemical bonding.[42] It has also been reported that the roughness of the titanium surface provides mechanical bonding with resin cement and is an important factor that affects the bond strength.[43] However, based on the data obtained from the present study, the authors believe that the increase in the retention values between the abutment surface and the crown is not only due to the roughness values and micromechanical bonding, but also due to chemical bonding, which also plays an important role.

The present authors also believe that new studies in which cements of different properties (eg, temporary

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cement, implant cement) and different superstructure materials (eg, precious metals, nonprecious metals, zirconium) are used together with sandblasting, H_2O_2 etching, atmospheric plasma, CMP, and TiO_2 sol-gel nanocoating surface treatments applied on abutments to evaluate surface roughness and retention values will contribute to the literature. Further studies are needed to evaluate the effect on retention of different treatments applied to inner crown surfaces.

CONCLUSIONS

Within the limitations of this study, the sandblasted group showed the highest surface roughness and retention value. The H_2O_2 etching group showed the highest retention value after the sandblasted group. The atmospheric plasma treatment provided a significantly higher retention value than the control group. In the CMP, TiO_2 nanocoating, and control groups, no significant difference was observed in the mean retention values, but the TiO_2 nanocoating group showed the lowest retention value. According to the results of this study, the authors believe that atmospheric and H_2O_2 etching treatments are effective methods to increase the retention of implant-supported fixed prostheses.

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REFERENCES

1. Steinemann SG. Titanium– the material of choice? Periodontol 2000 1998;17:7–21.
2. Ozdemir Z, Ozdemir A, Basim GB. Application of chemical mechanical polishing process on titanium based implants. Mater Sci Eng C Mater Biol Appl 2016;68:383–396.
3. Baburaj EG, Starikov D, Evans J, Shafeev GA, Bensaoula A. Enhancement of adhesive joint strength by laser surface modification. Int J Adhes Adhes 2007;27:268–276.
4. Kunt GE, Ceylon G, Yilmaz N. Effect of surface treatments on implant crown retention. J Dent Sci 2010;5:131–135.
5. Ramö J, Saarinen K, Sillanpää M. Uniform corrosion of titanium in alkaline hydrogen peroxide conditions: Influence of transition metals and inhibitors calcium and silicate. Mater Corros 2002;53:898–901.
6. Tengvall P, Lundström I, Sjöqvist L, Elwing H, Bjursten LM. Titanium-hydrogen peroxide interaction: Model studies of the influence of the inflammatory response on titanium implants. Biomaterials 1989;10:166–175.
7. Tengvall P, Elwing H, Sjöqvist L, Lundström I, Bjursten LM. Interaction between hydrogen peroxide and titanium: A possible role in the biocompatibility of titanium. Biomaterials 1989;10:118–120.
8. Tengvall P, Elwing H, Lundström I. Titanium gel made from metallic titanium and hydrogen peroxide. J Colloid Interface Sci 1989;130:405–413.
9. Pan J, Thierry D, Leygraf C. Electrochemical and XPS studies of titanium for biomaterial applications with respect to the effect of hydrogen peroxide. J Biomed Mater Res 1994;28:113–122.
10. Vogelsang A, Ohl A, Steffen H, Foest R, Schröder K, Weltmann KD. Locally resolved analysis of polymer surface functionalization by an atmospheric pressure argon microplasma jet with air entrainment. Plasma Process Polym 2010;7:16–24.
11. Basim GB, Brown SC, Vakarelski IU, Moudgil BM. Strategies for optimal chemical mechanical polishing (CMP) slurry design. J Dispers Sci Technol 2003;24:499–515.
12. Chathapuram VS, Du T, Sundaram KB, Desai V. Role of oxidizer in the chemical mechanical planarization of the Ti/TiN barrier layer. Microelectron Eng 2003;65:478–488.
13. He J, Ichinose I, Fujikawa S, Kunitake T, Nakao A. A general, efficient method of incorporation of metal ions into ultrathin TiO_2 films. Chem Mater 2002;14:3493–3500.
14. Bieniaś J, Surowska B, Stoch A, Matraszek H, Walczak M. The influence of SiO2 and SiO2-TiO2 intermediate coatings on bond strength of titanium and Ti6Al4V alloy to dental porcelain. Dent Mater 2009;25:1128–1135.
15. Djaoued Y, Badilescu S, Ashrit PV, Bersani D, Lottici PP, Robichaud J. Study of anatase to rutile phase transition in nanocrystalline titania films. J Sol-Gel Sci Technol 2002;24:255–264.
16. Velten D, Biehl V, Aubertin F, Valeske B, Possart W, Breme J. Preparation of TiO2 layers on cp-Ti and Ti6Al4V by thermal and anodic oxidation and by sol-gel coating techniques and their characterization. J Biomed Mater Res 2002;59:18–28.
17. Kajitvichyanukul P, Ananpattarachai J, Pongpom S. Sol-gel preparation and properties study of TiO_2 thin film for photocatalytic reduction of chromium(VI) in photocatalysis process. Sci Technol Adv Mater 2005;6:352–358.
18. Kern M, Thompson VP. Durability of resin bonds to pure titanium. J Prosthodont 1995;4:16–22.
19. Fonseca RG, de Almeida JG, Haneda IG, Adabo GL. Effect of metal primers on bond strength of resin cements to base metals. J Prosthet Dent 2009;101:262–268.
20. Di Francescantonio M, Oliveira MT, Daroz LG, Henriques GE, Giannini M. Adhesive bonding of resin cements to cast titanium with adhesive primers. Braz Dent J 2012;23:218–222.
21. Ozcan M, Valandro LF. Bond strength of two resin cements to titanium after different surface conditioning methods. Gen Dent 2012;60:e6–e12.
22. Kim JT, Cho SA. The effects of laser etching on shear bond strength at the titanium ceramic interface. J Prosthet Dent 2009;101:101–106.
23. Kurt M, Külünk T, Ural C, Külünk Ş, Danişman Ş, Savaş S. The effect of different surface treatments on cement-retained implant-supported restorations. J Oral Implantol 2013;39:44–51.
24. Kim Y, Yamashita J, Shotwell JL, Chong KH, Wang HL. The comparison of provisional luting agents and abutment surface roughness on the retention of provisional implant-supported crowns. J Prosthet Dent 2006;95:450–455.
25. Sahu N, Lakshmi N, Azhagarasan NS, Agnihotri Y, Rajan M, Hariharan R. Comparison of the effect of implant abutment surface modifications on retention of implant-supported restoration with a polymer based cement. J Clin Diagnostic Res 2014;8:239–242.
26. Kamijo K, Yoshida T, Mizoguchi T, Nagasawa S, Ito M. Evolution of H2O2 surface treatment for the adhesion between resin cements and titanium. J Jpn Soc Dent Mater Devices 2002;21:121–124.
27. Nagassa ME, Daw AE, Rowe WG, Carley A, Thomas DW, Moseley R. Optimisation of the hydrogen peroxide pre-treatment of titanium: Surface characterisation and protein adsorption. Clin Oral Implants Res 2008;19:1317–1326.
28. Daw AE, Kazi HA, Colombo JS, et al. Differential cellular and microbial responses to nano-/micron-scale titanium surface roughness induced by hydrogen peroxide treatment. J Biomater Appl 2013;28:144–160.
29. Elsaka SE, Swain MV. Effect of surface treatments on the adhesion of self-adhesive resin cements to titanium. J Adhes Dent 2013;15:65–71.
30. Yoshida T, Terashima N, Niiro T, et al. Bond strength of resin cements to H2O2-treated titanium plates. Dent Mater 2005;21:1087–1097.
31. Duske K, Koban I, Kindel E, et al. Atmospheric plasma enhances wettability and cell spreading on dental implant metals. J Clin Periodontol 2012;39:400–407.
32. Seker E, Kilicarslan MA, Deniz ST, Mumcu E, Ozkan P. Effect of atmospheric plasma versus conventional surface treatments on the adhesion capability between self-adhesive resin cement and titanium surface. J Adv Prosthodont 2015;7:249–256.

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33. El-Helbawy NG, El-Hatery AA, Ahmed MH. Comparison of oxygen plasma treatment and sandblasting of titanium implant-abutment surface on bond strength and surface topography. Int J Oral Maxillofac Implants 2016;31:555–562.
34. Foest R, Kindel E, Ohl A, Stieber M, Weltmann K-D. Non-thermal atmospheric pressure discharges for surface modification. Plasma Phys Control Fusion 2005;47:B525.
35. Kaufman FB, Thompson DB, Broadie RE, et al. Chemical-mechanical polishing for fabricating patterned W metal features as chip interconnects. J Electrochem Soc 1991;138:3460–3465.
36. Sittig C, Textor M, Spencer ND, Wieland M, Vallotton PH. Surface characterization of implant materials c.p. Ti, Ti-6Al-7Nb and Ti-6Al-4V with different pretreatments. J Mater Sci Mater Med 1999;10:35–46.
37. Advincula MC, Petersen D, Rahemtulla F, Advincula R, Lemons JE. Surface analysis and biocorrosion properties of nanostructured surface sol–gel coatings on Ti6Al4V titanium alloy implants. J Biomed Mater Res Part B Appl Biomater 2007;80:107–120.
38. Krzak-Roś J, Filipiak J, Pezowicz C, Baszczuk A, Miller M, Kowalski M, Bedziński R. The effect of substrate roughness on the surface structure of TiO(2), SiO(2), and doped thin films prepared by the sol-gel method. Acta Bioeng Biomech 2009;11:21–29.
39. Lim BS, Heo SM, Lee YK, Kim CW. Shear bond strength between titanium alloys and composite resin: Sandblasting versus fluoride-gel treatment. J Biomed Mater Res B Appl Biomater 2003;64:38–43.
40. Darvell BW, Samman N, Luk WK, Clark RK, Tideman H. Contamination of titanium castings by aluminium oxide blasting. J Dent 1995;23:319–322.
41. Elsaka SE. Effect of surface pretreatments on the bonding strength and durability of self-adhesive resin cements to machined titanium. J Prosthet Dent 2013;109:113–120.
42. Asmussen E, Peutzfeldt A. Surface energy characteristics of adhesive monomers. Dent Mater 1998;14:21–28.
43. Fonseca RG, Haneda IG, Almeida-Júnior AA, de Oliveira Abi-Rached F, Adabo GL. Efficacy of air-abrasion technique and additional surface treatment at titanium/resin cement interface. J Adhes Dent 2012;14:453–459.

Literature Abstract

Effect of Locally Applied Simvastatin on Clinical Attachment Level and Alveolar Bone in Periodontal Maintenance Patients: A Randomized Clinical Trial

The purpose of this double-blinded, randomized, controlled trial was to determine if local application of simvastatin (SIM) combined with minimally invasive papilla reflection and root planing (PR/RP) was effective in improving clinical attachment level (CAL), reducing probing depth (PD), and increasing interproximal bone height (IBH) in persistent 6- to 9-mm periodontal pockets in patients receiving periodontal maintenance therapy (PMT). A total of 50 patients with Stage III, Grade B periodontitis presenting with a 6- to 9-mm interproximal PD with a history of bleeding on probing (BOP) were included in the study. Experimental (PR/RP + SIM/methylcellulose [MCL]; n = 27) and control (PR/RP + MCL; n = 23) therapies were randomly assigned. Root surfaces were accessed via reflection of the interproximal papillae, followed by RP assisted with endoscope evaluation, acid etching, and SIM/MCL or MCL application. CAL, PD, BOP, presence of plaque, and IBH (using standardized vertical bitewing radiographs) were evaluated at baseline and 12 months. Measurements were compared by group and time using chi-square, Wilcoxon rank-sum, and t tests. Both PR/RP + SIM/MCL and PR/RP + MCL, respectively, resulted in improvements in clinical outcomes (CAL: –1.9 ± 0.3 mm, P < .0001; and –1.0 ± 0.3 mm, P < .003; PD: –2.3 mm ± 0.3, P < .0001; and –1.3 mm ± 0.3, P < .0001; BOP: –58.7% and –41.7%, P < .05) and stable IBH (–0.2 ± 0.12, –0.4 ± 0.2, P = .22) from baseline to 12 months posttreatment. PR/RP + SIM/MCL showed more improvement in CAL (P = .03), PD (P = 0.007), and BOP (P = .047). The addition of SIM/MCL to PR/RP improved CAL, PD, and BOP compared to PR/RP alone in periodontal maintenance patients.

Killeen AC, Krell LE, Bertels M, et al. *J Periodontol* 2022;93(11):1682–1690. **References:** 21.
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Literature Abstract

Prospective Clinical Multicenter Study Evaluating the 5-Year Performance of Zirconia Implants in Single-Tooth Gaps

In recent years, ceramic implants made of zirconia have secured a niche position next to established titanium implants, due partly to new scientific findings and positive clinical experience with the handling of ceramic implants. The aim of this study was to assess the clinical and radiographic data for monotype ceramic implants that had remained in place for 60 months under masticatory loading. In 2011, this prospective clinical study included patients with a single-tooth gap in the maxilla and mandible. Monotype ceramic implants (Straumann) were used according to a standard protocol. Provisional prostheses were placed after 3 months, followed by final prostheses 3 months later. Patients were invited for a 60-month follow-up. Implant survival was analyzed from lifetime data. Success rates and crestal bone levels were evaluated from implant placement to 6, 12, 36, and 60 months after surgery. From the initial 44 patients recruited, 36 were available for analysis at the 60-month follow-up. With one implant lost before the 6-month follow-up, the survival rate after 60 months was 97.7%, and the mean survival time was 58.7 months. Sixty months after implant placement, the success rate was 97.2% (95% CI: 84.6% to > 99.9%). Mean bone loss after 60 months was 0.99 (± 0.59) mm. After 60 months, monotype ceramic implants made of zirconia achieved success and survival rates comparable to those reported for titanium implants in select patient populations. Ceramic implants can be used as an alternative to titanium implants at the request of patients and if specifically indicated; for example, due to titanium intolerance.

Gahlert M, Kniha H, Laval S, Gellrich NC, Bormann KH. *Int J Oral Maxillofac Implants* 2022;37:804–811. **References:** 20. **Reprints:** M. Gahlert, mg@oralchirurgie-tl.de —*Steven Sadowsky, USA*

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