The purpose of this study was to evaluate the effects of the various surface treatment methods on the retention of single crowns on implant abutments. The study included 50 single crowns that were cemented with adhesive resin cement onto the ITI solid abutments. The specimens were randomly divided into 5 groups, each including 10 specimens according to the following surface treatments: group C, control, abutments remained unaltered as control; group L, etching with CO2 laser; group SB, sandblasting with 50-μm Al2O3; group MS: coating with titanium nitride (TiAlN) with a radiofrequency magnetron sputtering system; and group SP, silicoating by Silano-Pen. After the surface treatment procedures were finished, the casted crowns were cemented onto the abutments, and thermocycling was applied to simulate oral environment. The uniaxial tensile force was applied to all test crowns using a universal test machine (Instron) with a crosshead speed of 0.5 mm/min. The load required to dislodge each crown was recorded in Newton. The lowest tensile bond strength values were obtained with group MS (223.26 ± 14.30 N) and significantly differ from all other groups except group C. Group SB showed highest test results (506.02 ± 18.04 N) and differs from other groups (P < .05). The test values that were obtained in group MS-group C did not show significant differences (P > .05). Sandblasting is an effective method to increase bond strength. Also, Silano-Pen and laser application is advisable for increasing the crown retention to abutments. Titanium aluminum nitride coating with magnetron sputtering technique seems to be ineffective.

**Key Words:** implant abutment, retention, coating, surface treatment, laser

---

**INTRODUCTION**

Increasing numbers of edentulous and partially edentulous patients are being treated with implant-supported prostheses. The long-term success of dental implants is well-documented. Cast fixed partial prostheses for these patients may be screw-retained or cement-retained restorations. Both of them have some advantages and disadvantages. Screw-retained implant-supported prostheses may require additional maintenance because screws may loosen or break, and these prostheses can also cause esthetic problems in the anterior region. However, screw-retained prostheses are also associated with nonpassive superstructures, partially unretained restorations resulting from loosening or breakage of fastening screws and rapid loading of the implant interface. Cement-retained crown is a choice for many patients who receive implants for several reasons, including esthetics, occlusal stability, overcoming angulation problems, and the fabrication of a passively fitting restoration. Cement-retained prostheses, on the other hand, allow for optimal esthetics and occlusion. The crown retention on
abutment may cause significant problems for both clinician and patient, so luting agents should eliminate problems noted with screw-retained prostheses. Singer and Serfaty\(^4\) reported success in cast restorations that were retained with provisional luting agents. It has also been advocated that the luting agent may act as a shock absorber.\(^4\)

In particular, the choice of the appropriate cement for a specific clinical situation is still based on the clinician’s experience rather than specific data. Ideally, the cement should be strong enough to indefinitely retain the prosthesis in place, yet weak enough to allow the dentist to retrieve it if necessary.\(^5\) Factors that may affect the retention of the provisional restoration are the geometry of abutment preparation, abutment taper or parallelism, surface area, abutment height, surface finish or roughness, and luting agent.\(^3,6\) It has been stated that for tooth preparation, a 6\(^\circ\) taper is ideal. This is why most manufacturers machine their abutments to a 6\(^\circ\) taper.\(^3\) Surface roughness and luting agents are factors that can be controlled by the clinician.\(^7\) Surface roughness increases the retention due to resulting microretentive areas. As reported, surface roughness enhanced crown retention as much as 31\%.\(^7\) Due to the improvement of lasers in dentistry, laser treatments are thought to be an alternative method to other surface treatment methods because of their optical penetration depth.\(^8\)

In dentistry, various surface coatings, including tin oxide, titanium aluminum nitride (TiAlN), titanium nitride (TiN), aluminum (Al), aluminum nitride (AlN), gold, silicon nitride, calcium phosphates, glass composites, bioactive phosphosilicate glasses, glass ceramics, and hydroxyapatite have been reported.\(^9-15\) They were designed also for alloys and ceramics used for fixed partial dentures and prosthetic metallic implants.\(^9\)

Coatings have often been applied to dental alloys to improve the mechanical properties of the metallic dental alloy (hardness, wear, and corrosion resistance) and to provide good biocompatibility.\(^16-18\) In previous studies, TiN and TiAlN coatings were used to minimize the oxidation and to enhance adhesion of dental porcelain and composite resin to titanium for titanium-ceramic restorations.\(^16,19\)

Silane coupling on metallic surface can be made with various methods. Tribochemical silica coating (Rocatec, CoJet), Silicoater Classic, Silicoater MD, and Siloc are some of these methods.\(^20\) While tribochemical silica coating is a specially engineered grit-blasting system based on special chemically designed silica-coated alumina particles for extraoral conditioning of the substrate surface, Silicoater Classic, Silicoater MD, and Siloc are pyrochemical silica-coating technologies based on the use of elevated temperatures.\(^20\)

A few years ago, a modification of the Silicoater technology concept was introduced. Silano-Pen is the chairside version of Silicoater technology (Silicoater MD, Heraeus Kulzer, Wehrheim, Germany), applied by a hand held device (Silano-Pen or PyrosilPen); using a flame treatment approach, could deliver reliable adhesion.\(^20-22\)

There are a lot of studies about bond strength between crown and implant abutment related with different luting agents.\(^3,23,24\) But, there are limited studies that evaluate the surface-treated abutment retention to cement-retained restorations. As for different treatments such as TiAlN coating and silicoating by Silano-Pen on implant abutments, no experimental research has been undertaken to date.

The purpose of this study was to compare and evaluate the effect of different surface treatment methods on tensile bond strength of abutments and cement-retained restorations. It was hypothesized that the bond strength achieved between the implant abutments and the crown restorations was affected by the various surface treatment methods applied on the surface of abutments.

**MATERIALS AND METHODS**

Fifty ITI solid abutments, 4 mm high, and 50 implant analogs, burn out copings (Straumann, Basel, Switzerland) were used in this study. Autopolymerizing acrylic resin (Meliodent, Bayer Dental, Germany) blocks were fabricated, allowing the implant analogs to be placed in the blocks perpendicular to the block by the help of a parallelometer (Paraskop, Bego Dental, Bremen, Germany) (Figure 1). Fifty abutments were divided into 5 groups based on the surface treatment applied. They are described below.

Group C (control): abutment’s surfaces were left untreated.

Group L (laser etched): abutment’s surfaces were irradiated by CO\(_2\) laser (Smart US20D, Deka, Florence, Italy). Laser energy was delivered in a pulse mode with a wavelength of 10.6 \(\mu\)m, pulse...
repetition rate of 1000 Hz, and pulse duration of 160 ms at an average power setting of 3W.

Group SB (sandblasted): abutment’s surfaces were abraded with 50 μm alumina oxide (Al₂O₃) particles (Korox 50, Bego) applied perpendicular to the surface at 3 bar pressure for 10 seconds at 10 mm. After abrasion, the test specimens were thoroughly rinsed with water spray for 30 seconds then dried with oil-free air.

Group MS (TiAlN coated): abutment’s surfaces were coated with titanium nitride (TiAlN) with a reactive magnetron sputtering system; TiAlN coatings were deposited by a dual magnetron sputtering system as shown in Figure 2 using a compound target (50% Ti, 50% Al) with a size of about 645 mm × 110 mm × 10 mm. The system has a stainless steel vacuum chamber (600 mm in diameter and 800 mm in height) and two unbalanced planar magnetrons powered by 2 independent 12 kW DC generators (12 MDX, Advanced Energy, Fort Collins, Colo). All of the substrates (implants) were ultrasonically cleaned in acetone and alcohol for 15 minutes each, rinsed in distilled water, and dried before being placed into the depositing chamber. Furthermore, cleaning was done using argon bombardment at a negative DC substrate bias voltage of 850 V with argon gas to a pressure of 5 mtorr prior to the deposition in the chamber. The chamber was evacuated to a vacuum of $3.4 \times 10^{-2}$ mtorr and backfilled with argon gas to a pressure of 5 mtorr. Firstly, the target was sputter cleaned in pure argon in order to remove oxide and nitride layers on the target surface. Then, as mentioned above, the substrates were cleaned. To improve the adhesion of the layers on the substrates, a thin TiAl interlayer was deposited prior to TiAlN coating at a constant argon gas pressure of 1.5 mtorr. Then, high purity nitrogen gas (99.998%) was introduced to the system. In the experiment, the flow rate of nitrogen (16 sccm) and the flow rate of argon (15 sccm) were controlled by mass flow controllers. Al and Ti target powers were constant at 3000 W, and substrate bias

**Figures 1–4.** Figure 1. Placing implant analogs to acrylic block. Figure 2. Schematic illustrations of magnetron sputtering coating system. Figure 3. Torqued abutments. Figure 4. Pulling the crowns from the abutments.
Voltage was about \(-100\) V. During the deposition process, the temperature of the chamber was about 80°C, as measured by a thermocouple. A stainless steel substrate holder was designed as seen in Figure 2. The substrates came across the compound target once in every rotation. The deposition time was 120 minutes. The thickness of the coatings deposited on the substrates was measured by ball-cratering method. The deposition conditions are also summarized in Table 1.

Group SP (flamed with Silano-Pen): abutment’s surfaces were flamed with the Silano-Pen device (Bredent GmbH, Senden, Germany) for 5 s/cm². After cooling down to room temperature, the Silano-Pen bonding agent (alcoholic solution of 3-methacryloyloxypropyltrimethoxysilane) was brushed on and air-dried for 3 minutes. After surface treatment procedures, the abutments were connected to the implant analogs and torqued to 35 N-cm (Figure 3). Crown copings were constructed by the same operator with the help of the prefabricated plastic burn-out copings of height 7 mm (plastic coping 048.605, Straumann). Wax rings were added to the occlusal portion of the waxed copings for attachment to the tensile testing device. The waxed patterns connected to plastic burn-out copings were sprued, invested, and cast with an alloy (Wiron 99, Bego), which contains 65% nickel, 22.5% chrome, 9.5% molybdenum, 1% niobium. Adhesive resin cement (Panavia F2.0, Kuraray, Osaka, Japan) was used for cementing the casted crowns. Luting agents were mixed according to the manufacturer recommendations, and a thin layer was placed in the crowns, and they were placed onto the abutments and held in place with finger pressure for 10 seconds and were then placed under a 5 kg pressure for 10 minutes at room temperature. Excess luting agent was removed with a cotton pellet.

After the cementation, the test specimens were stored in distilled water at 37°C for 24 hours and then thermocycled between 5°C and 55°C with 30-second dwell times for 5000 cycles. The acrylic blocks with the abutments were mounted in a universal testing machine (Lloyd LRX, Lloyd Instruments PIC, Fareham, Hampshire, UK). Each specimen was pulled from the abutment at a crosshead speed of 0.5 cm/min, and the ultimate tensile strength was recorded as Newton (Figure 4). Tensile bond strengths of the specimens were statistically analyzed by one-way analysis of variance (ANOVA) and post-hoc Tukey tests (\(\alpha = .05\)).

To evaluate the effect of surface treatments methods on abutments, 5 additional samples were prepared. Four of the specimens were treated with the same experimental protocol as described previously. All specimens were coated with gold using a sputter coater (S150B, Edwards, Crawley, UK) and examined under a field emission scanning electron microscope (SEM) (CSM-6335F, JEOL, Tokyo, Japan) at 20 kV. The SEM photomicrographs were developed with \times 250 magnification for visual inspection (Figure 5).

**RESULTS**

The results of one-way ANOVA (Table 2) indicated that the surface treatment methods affected the retention values significantly; the mean tensile bond strength values are presented in Table 3. The lowest tensile bond strength values were obtained with group MS (223.26 ± 14.30 N) and significantly differ from all other groups except group C. Group SB showed highest test results (506.02 ± 18.04 N) and differs from other groups (\(P < .05\)). The test values that were obtained in group MS-group C did not show significant differences (\(P > .05\)).

SEM images of treated implant abutment surfaces are shown in Figure 5. When compared with the control (Figure 5a), the laser-irradiated abutment surfaces exhibited microcracks and macrorretainive areas (Figure 5b). The sandblasted surface of the implant abutment showed distinct irregularities (Figure 5c). The abutment surface that is subjected to TiAlN coating showed smooth surfaced (Figure 5d). Treatment with Silano-Pen (Figure 5e) did not change the superficial structure when compared with the control.

<table>
<thead>
<tr>
<th>Table 1: Deposition parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating TiAlN</td>
</tr>
<tr>
<td>Substrate Ti implants</td>
</tr>
<tr>
<td>Bias voltages (–V)</td>
</tr>
<tr>
<td>(N_2) pressures (mtorr)</td>
</tr>
<tr>
<td>Total working gas pressures (Ar+(N_2)) (mtorr)</td>
</tr>
<tr>
<td>Target power (W)</td>
</tr>
<tr>
<td>Coating time (min)</td>
</tr>
<tr>
<td>Thickness of the coating (μm)</td>
</tr>
</tbody>
</table>

_Kurt et al._

Downloaded from http://www.joionline.org/doi/pdf/10.1563/AAID-JOI-D-10-00151 by guest on 25 February 2020
Within the limitations of the present study, it can be concluded that our hypothesis was particularly confirmed; the bond strengths between the abutments and the crown restorations were significantly affected by the investigated surface treatments, except TiAlN coating.

The ITI solid abutment is a titanium color-coded abutment with a distinctive nonrotational surface comprising one grooved and flat side. It is supplied with a prefabricated burn-out cap that snaps onto the abutment and eliminates the need for die spacer. A 4-mm high solid abutment presented a relatively short, smooth surface. Various types of intraoral forces and their combinations may induce high stress at the interface between an abutment and cement layer, which results in crown dislodgement. Therefore, when short abutments were used such as 4 mm high, an additional retention is needed especially for single implant crown restorations.

In the present study, the effect of surface treatment performed on the solid abutment was evaluated for its effect on the retention of short abutments. It is well accepted that sandblasting with alumina particles results in an increased surface roughness and surface area. Kim et al. stated that surface modification with either airborne-particle abrasion or treatment with a diamond rotary cutting instrument would be an effective way to improve retention when TempBond is used, and added that surface modifications by airborne-particle abrasion and by treatment with a diamond rotary cutting instrument would be

<p>| Table 2 |
| One-way analysis of variance (ANOVA) results |</p>
<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>553225.818</td>
<td>4</td>
<td>138306.454</td>
<td>211.470</td>
</tr>
<tr>
<td>Within groups</td>
<td>29431.014</td>
<td>45</td>
<td>654.023</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>582656.832</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sig indicates significance.

<p>| Table 3 |
| Mean (Newton) and SD values of tensile bond strength values |</p>
<table>
<thead>
<tr>
<th>Group</th>
<th>Surface Treatment Method</th>
<th>Newton (±SD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Control</td>
<td>249.41 (±15.39) a</td>
</tr>
<tr>
<td>L</td>
<td>Laser etched</td>
<td>315.14 (±29.86) b</td>
</tr>
<tr>
<td>SB</td>
<td>Sandblasted</td>
<td>506.02 (±18.04) c</td>
</tr>
<tr>
<td>MS</td>
<td>TiAIN coated</td>
<td>223.26 (±14.30) a</td>
</tr>
<tr>
<td>SP</td>
<td>Flamed with Silano-Pen</td>
<td>412.91 (±40.15) d</td>
</tr>
</tbody>
</table>

*Values having same letters were not significantly different for post-hoc Tukey test (P > .05).
similarly effective for better retention. Similarly, we observed that the sandblasting group showed the highest bond strength values when compared with the others.

Since the development of the ruby laser in 1960, lasers have become widely used in medicine and dentistry. The carbon dioxide (CO₂) and Nd:YAG lasers are the most generally used instruments for both intraoral soft tissue surgery and hard tissue applications. By varying a number of parameters (pulse mode, irradiation time, frequency, and energy outputs), several types of lasers have been indicated for dental treatments. Murray et al indicated that laser treatment may be a suitable alternative to airborne-particle abrading or other surface pretreatment techniques for enhancing the bond strength of dental materials to metal surfaces.

Gaggl et al reported that laser processing is a new method of treating implant surfaces to produce a high degree of purity with adequate surface roughness, in comparison with other surface treatments. Cho and Jung also demonstrated that laser etching is an effective method for producing an appropriate surface roughness for titanium. It was also reported that laser and electron-beam thermal treatments could be used for modification of the microstructure of titanium surfaces without contamination, providing optimal roughness; laser treatment would be an effective method for producing surface roughness without any contamination.

In the present study, although the laser-treated group showed higher values than the control group, but lower values than the sandblasting and Silano-Pen groups, laser treatment could not create the microretentive areas as sandblasting did. Although laser treatment has been pointed out as a promising technology in dentistry, there is still need of more research to determine appropriate parameters of laser treatment for application of this technology on dental materials.

In previous studies, TiN and TiAlN coatings were used to enhance adhesion of porcelain veneer to titanium alloy and composite resin to gold, platinum, and silver alloy, and TiN coating increased bond strength of composite resin to titanium. TiAlN coatings show a number of mechanical and technical characteristics (eg, high hardness, low wear, corrosion resistance, and oxidation resistance at high temperature). In addition, the color of the TiAlN film can be modified by varying the composition. Thus, it has a potential for use in dental prostheses.

Tanaka et al stated that TiN coating increased the bond strength of composite resin to Au-Pd-Ag alloy due to the microscopic surface irregularities of the TiN coating. In the present study, it was expected that TiAIN coating would increase the bond strength values between abutment and resin cement; however, this was not so as the lowest bond strength values were obtained with TiAIN coating and no significant difference were observed between the TiAIN-treated group and the control group. TiAIN coating created smooth surfaces (Figure 5d) that had negatively affected the micro-mechanical retention.

Results of this study demonstrated that the Silano-Pen–treated group showed higher bond strength values than all groups, except the sandblasting group. Silicoating with Silano-Pen (equivalent with the PyrosilPen) technology is fast and trouble-free and is an effective surface treatment method for achieving very good bond strength between resin cements and restorative materials (metals and ceramics). Silano-Pen creates a very thin silicon dioxide-type layer on the alloy's surface by decomposing silanes during flaming. It was stated that heat application on metals and ceramics increases surface hydroxyl groups.

Tensile bond strength of the luting agent must be great enough to resist lateral and vertical forces during function. Polycarboxylate cements and so-called self-adhesive resins seem to be appropriate luting agents for permanent fixation because of their high retentive values. Crowns and fixed partial dentures cemented on implant abutments with these kinds of cement will have a lower risk of retention loss. When using smooth titanium implant abutments, the greater compressive strength of zinc phosphate cements compared to polycarboxylate and zinc oxide cements probably does not play a major role in providing retention. When choosing the cement, the clinician should carefully evaluate the height and the taper of the abutments, and also be aware of the relative retentive values of the available luting agents. The longer and more parallel the abutments are, the less retentive the cement can be. In the presence of short, tapered abutments, zinc oxide cements should be avoided.
in favor of more retentive cements. When short abutments are employed, a reduced convergence angle is required to achieve adequate retention. Unfortunately, there are no indications of which cement is the most indicated.

In our study, the control group was not modified with any treatment and therefore relatively smooth. This could have decreased cement abutment micro-mechanical interlocking, leading to decreased cement retention values. In the present study, one type of cement was used. Further investigations are needed to evaluate the effect of different luting cements.

Within the limitations of the present study, it can be concluded that when short abutments have to be used due to the limited interocclusal space, to increase the retention of restorations, sandblasting is an effective method to increase bond strength. Also, Silano-Pen and laser application is advisable for increasing the crown retention to abutments. Titanium aluminum nitride coating with magnetron sputtering technique seems to be ineffective.

ABBREVIATIONS

Al: aluminum
Al2O3: alumina oxide
AlN: aluminum nitride
ANOVA: analysis of variance
CO2: carbon dioxide
SEM: scanning electron microscope
TiAIN: titanium aluminum nitride
TiN: titanium nitride

REFERENCES


