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# Retention of zirconia copings over smooth and airborne-particle-abraded titanium bases with different resin cements

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## ABSTRACT

**Statement of problem.** How cement type and the surface treatment of a titanium base affect the retention of zirconia copings on titanium bases is unclear.

**Purpose.** The purpose of this in vitro study was to evaluate the dislodging forces of zirconium oxide copings cemented on implant-supported titanium bases with different luting agents and to examine the influence of airborne-particle abrasion on titanium surfaces.

**Material and methods.** Thirty implant laboratory analogs (BioHorizons) were fixed in metal blocks, and 30 prosthetic titanium bases (BioHorizons) were tightened with 35 Ncm of torque. Zirconium oxide copings with a luting-gap size of 30 μm were produced by using the Lava (3M ESPE) technology. The specimens were bonded to the titanium bases with 3 different resin cements (G-CEM LinkAce, RelyX U200, and Ceka Site). The specimens were kept in artificial saliva at 37°C for 24 hours and then subjected to a dynamic loading of 5000 cycles with a mastication simulator (SD Mechatronic) with thermocycling between 5°C and 55°C. The tensile force was measured by using a universal testing machine (Zwick/Roell) at a crosshead speed of 5 mm/min. After the measurement, the cement was cleaned from the titanium bases and zirconia copings. The titanium bases were airborne-particle abraded with 50-μm aluminum oxide ($Al_2O_3$) particles, and the bonding process was repeated. The statistical analysis included descriptive analysis, 2-way ANOVA, the Tukey post hoc, and simple main effect tests ($\alpha$=.05).

**Results.** Bond strengths were significantly different according to the cement type used and before and after airborne-particle abrasion ($P$<.05). The cement retentiveness before airborne-particle abrasion was as follows: G-CEM LinkAce (1338 ±69 N)>RelyX U200 (665 ±36 N)>Ceka Site (469 ±22 N). The differences among all the cement types before airborne-particle abrasion were statistically significant ($P$<.05). After airborne-particle abrasion, retention decreased in all the groups, and the ranking of the cements' retentiveness remained the same: G-CEM LinkAce (662 ±65 N)>RelyX U200 (352 ±21 N)>Ceka Site (122 ±17 N). After airborne-particle abrasion, the differences among all the cements remained statistically significant ($P$<.05). The comparison within the groups before and after airborne-particle abrasion revealed that abrading the titanium bases with 50-μm $Al_2O_3$ decreased the bond strength for all the tested cements.

**Conclusions.** The cement type had a significant influence on the retention of the zirconia copings, and abrading the titanium bases with 50-μm $Al_2O_3$ significantly decreased the dislodging force of the coping from the titanium base. (J Prosthet Dent 2019;121:949-54)

Zirconium oxide implant abutments can be obtained as 1 piece or cemented onto titanium bases. Cemented zirconia abutments have high strength because of the metal-to-metal interconnection that supports the zirconia.[1-4] One-piece zirconia abutments are declining in popularity due to clinical complications such as fracture of the engaging part inside the implant and internal wear of the implant-abutment interface.[3] Titanium base abutments have become the preferred treatment choice in today's implant dentistry.[5]

A reliable bond between the zirconia, cement, and the titanium base is essential for the longevity of the restoration. Typically, the retentive part of the titanium base should be about 4 to 6 mm in height; however, titanium bases with a height of only 3.5 mm are marketed, which may not provide sufficient retention. A

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## Clinical Implications

The retention of zirconia copings over titanium bases can be improved by choosing an appropriate type of resin cement. Knowledge of retention values can facilitate cement selection. Airborne-particle abrasion of titanium bases can decrease the retentive strength of zirconia copings.

large interocclusal distance may also increase the possibility of decementation between the titanium base and the zirconia coping. Factors important for the retention of cemented restorations include the cement type, luting gap, geometry, height, surface area, and roughness of the abutment.[6-15] The influence of cement type on the retention of implant-supported restorations has been investigated, but because metal suprastructures were studied,[16-21] these data cannot be relied upon in the case of zirconia restorations.

Computer-milled zirconia prostheses for implants usually do not have mechanical retention to ensure passive fit of the restoration; therefore, a stronger cement and higher retention are indicated.[22,23] The retentive force of zirconium oxide crowns on titanium abutments has been investigated, and much attention has been drawn to the composition of self-adhesive resin cements. The application of methacryloyloxydecyl-dihydrogen-phosphate monomer-containing resins has been reported to increase the retention of zirconium dioxide restorations.[24-26] However, information is insufficient regarding the retention of zirconia copings luted on titanium bases.[9,19,27-29]

Regardless of abutment height and geometry, the bond strength between the luting agent and the bonding surfaces is determined by the strength of the chemical bonds, mechanical interlocking, and surface roughness. Airborne-particle abrasion of titanium bases is intended to increase the bond strength through micromechanical bonding.[30] Aluminum oxide ($Al_2O_3$) is the most commonly used particles for this purpose. However, studies show conflicting results on the effect of airborne-particle abrasion on the bond strength of luting agents to metal substructures, many of them reporting a reduction of retention.[7,21,31-35]

The purpose of this study was to evaluate the retention value of zirconium oxide copings bonded to titanium bases with different resin cements and to study the effect of airborne-particle abrasion of titanium bases. The null hypotheses were that neither cement nor airborne-particle abrasion of the titanium base would influence the retention of zirconium oxide copings.

## MATERIAL AND METHODS

The experiment was carried out in 2 stages. Initially, 30 implant analogs of 4.0 mm in diameter (Tapered Internal; BioHorizons IPH, Inc) were vertically embedded in metal blocks. Thirty prosthetic titanium bases of 5 mm height (Titanium base abutment; BioHorizons IPH, Inc) were placed in each implant analog and tightened to 35 Ncm. Thirty zirconium oxide copings (Lava Classic; 3M ESPE Dental Products) were designed and milled using the Lava technology (3M ESPE Dental Products). The copings were sintered at 1500°C for 8.5 hours. The zirconium oxide copings were evaluated for accuracy using a silicone-disclosing medium (Fit Checker; GC Co) and fitted to the titanium bases. All misfit implants were corrected by grinding the intaglio surface of the coping until a satisfactory fit was reached. Marginal accuracy was inspected under a microscope (ZEISS EyeMag Pro; ZEISS) at ×3.2 magnification.

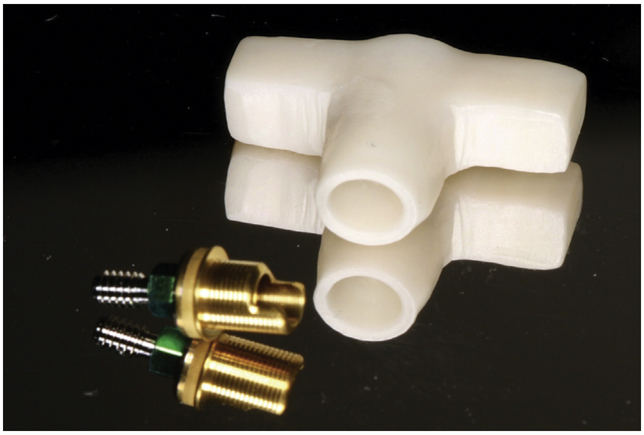

**Figure 1.** Zirconia coping and original titanium base (BioHorizons).

The bonding surfaces of all the copings were cleaned using 96% isopropyl alcohol. All the specimens with a luting-gap size of 30 μm were bonded to the titanium bases (Fig. 1) by using 3 different resin cements: G-CEM LinkAce (GC Co); RelyX U200 (3M ESPE Dental Products); and Ceka Site (CEKA PRECI-LINE) (Table 1). All the cements were dispensed from syringes with automixing tubes onto the intaglio surface of the zirconia copings and equally distributed on all the walls using a brush. The copings were then gently pressed on the titanium bases until complete seating was ensured. Excess cement was brushed off, and each surface for G-CEM LinkAce (GC Co) and RelyX U200 (3M ESPE Dental Products) was light polymerized for 20 seconds. No light polymerization was carried out for Ceka Site (CEKA PRECI-LINE) as this cement is autopolymerizing. After light polymerization, the copings were autopolymerized for an additional 4 minutes.

The implant analog-abutment-coping assemblies were stored in physiological saline solution at 37°C for 24 hours, after which the specimens were dynamically loaded for 5000 cycles in a mastication simulator

**Table 1.** Tested materials, type, and composition

| Material | Type | Composition |
|---|---|---|
| G-CEM LinkAce (GC Corp) | Dual polymerizing, self-adhesive, automix | Paste A: fluoroalumino silicate glass, initiator, urethane dimethacrylate (UDMA), dimethacrylate, pigment, silicon dioxide, inhibitor; Paste B: silicon dioxide, UDMA, dimethacrylate, initiator, inhibitor |
| RelyX U200 (3M ESPE) | Dual polymerizing, self-adhesive, automix | Base paste: methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives; Catalyst paste: methacrylate monomers, alkaline (basic) fillers, silanated fillers, initiator components, stabilizers, pigments, rheological additives |
| Ceka Site (CEKA PRECI-LINE) | Autopolymerizing, automix | Paste of dimethacrylates, titanium dioxide, silicon dioxide, catalysts, stabilizers, and pigments; Contains: <32% UDMA, <8% decamethylene dimethacrylate, <1% benzoyl peroxide |

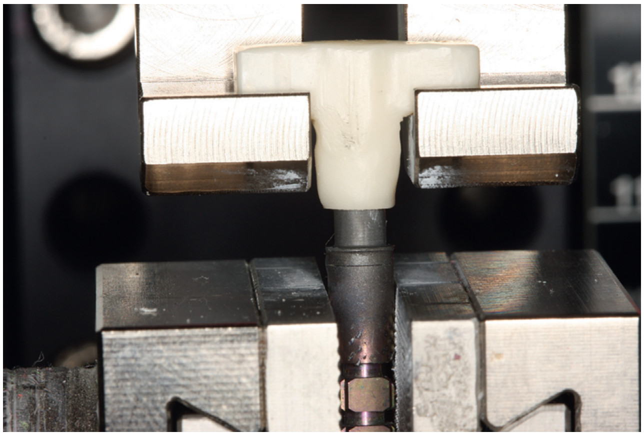

**Figure 2.** Tensile load applied until separation of copings.

**Figure 3.** Airborne-particle-abraded titanium bases.

(Klausimulator CS-4.2; SD Mechatronic) with a 30-second dwell time and with thermocycling at a temperature of between 5°C and 55°C. The tensile dislodging force was measured in Newtons using a universal testing machine (Z2.5; Zwick/Roell) at a crosshead speed of 5 mm/min (Fig. 2).

Subsequently, the cement was cleaned from the titanium bases and zirconia copings. Visual inspection of the debonded specimens showed that most of the cement remnants had adhered to the surface of the titanium bases. The intaglio surfaces of the zirconia copings were cleaned of cement remnants with a sharp explorer, steam cleaned, and cleaned using 96% isopropyl alcohol. The cement from the titanium bases was eliminated by airborne-particle abrasion using 50-µm $Al_2O_3$ (Aluminium oxide, Eisenbacher Dentalwaren; ED GmbH) at 0.2-MPa pressure perpendicular to each surface from a distance of 10 mm for 10 seconds (Fig. 3), and the sequence of the initial stage of the experiment was repeated.

The statistical analysis included descriptive analysis, a 2-way ANOVA to examine the effect of the cement and airborne-particle abrasion on the retention strength, the Tukey post hoc test, and simple main effect tests. The tests were performed using a statistical software program (IBM SPSS Statistics, v22; IBM Corp) ($\alpha$=.05).

## RESULTS

The mean retentive values and standard deviations before and after airborne-particle abrasion of titanium bases are presented in Table 2. A statistically significant interaction was found between the effects of the cement and the airborne-particle abrasion on the retention ($P<.05$). The Tukey post hoc test revealed significant differences in the retention strength among the different cement types before and after the airborne-particle abrasion ($P<.05$). However, the simple main effect analysis showed that G-CEM LinkAce (GC Co) lost significantly more retention strength after airborne-particle abrasion than the other types of cement ($P<.05$) (Fig. 4).

## DISCUSSION

The results of the study support the rejection of the null hypothesis that different types of cement do not influence the retention of zirconia copings over titanium bases. The type of resin cement altered the retentive strength of zirconia copings bonded to both intact and airborne-particle-abraded titanium bases ($P<.05$). In the past, standard stock abutments of various heights were used in this kind of study. Titanium bases represent different conditions compared with stock prosthetic

**Table 2.** Descriptive statistics (mean ±standard deviation) of dislodging forces (N) before and after airborne-particle abrasion of titanium bases

| Luting Agent | Nonabraded Titanium Bases | Airborne-Particle-Abraded Titanium Bases |
|---|---|---|
| G-CEM LinkAce (GC Co) | 1338 ±69 | 662 ±65 |
| RelyX U200 (3M ESPE Dental Products) | 665 ±36 | 352 ±21 |
| Ceka Site (CEKA PRECI-LINE) | 467 ±22 | 122 ±17 |

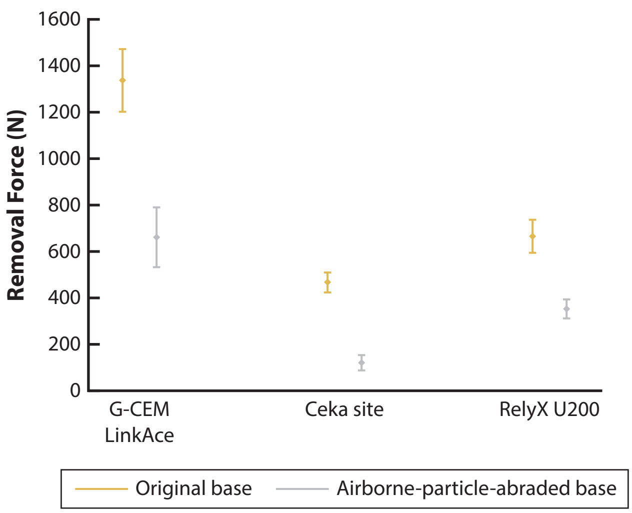


**Figure 4.** G-CEM LinkAce (GC Co) lost significantly more retention strength after airborne-particle abrasion than the other types of cement ($P<.05$). CI, confidence interval.

abutments because titanium bases typically have mechanical interlocking and less taper; therefore, this situation requires new evidence.

The retentive strength of different cements such as glass ionomer, resin-modified glass ionomer, resin cements, and other cements used for luting different copings over implant-supported metal abutments has been investigated.[11,16-18] The findings suggested that resin cements provided the highest retention values.[12,13,18,27] Thus, in the present study, only resin cements were selected for the analysis. Previous studies investigated metal copings, which incorporate some degree of frictional fit. Computer-aided design and computer-aided manufacturer (CAD-CAM) restorations have more passive fit, possibly impacting retention; therefore, the retention provided by the cement becomes even more important. Carnaggio et al[18] reported that adhesive resin cements were more retentive than resin-modified glass-ionomers in retaining ceramic crowns to implant abutments.

Not all types of resin cements, however, have demonstrated similar retentive forces. The highest retention was achieved when phosphate monomers were present in the cements' composition.[14] This result is consistent with that of the present study, as the highest dislodgement forces were achieved with G-CEM LinkAce (GC Corp), followed by RelyX U200 (3M ESPE) resin cement. The manufacturers report that G-CEM LinkAce (GC Corp) contains special ester phosphate monomers. In addition, RelyX U200 (3M ESPE) has methacrylate monomers, enclosing phosphoric acid groups.[14] When different phosphate monomers such as 6-methacryloxyhexyl dihydrogen phosphate, 10-methacryloxydecyl dihydrogen phosphate, or other monomers contact zirconia, the hydrogen group of monomer and the oxygen group of zirconia slowly produce water molecules and form a stable covalent bond.[15,24] The length of the -$(CH_2)$n chain determines the ability of different phosphoric monomers to enhance bonding.[25] Differences in composition may be why G-CEM LinkAce (GC Corp) cement demonstrated higher retention than RelyX U200 (3M ESPE). In a recent study of Lee et al,[26] self-adhesive resin cements were investigated, and G-CEM LinkAce (GC Co) showed greater shear bond strength than RelyX U200 (3M ESPE).

Nejatidanesh et al[19,27] studied the impact of titanium abutment height on the retention of implant-supported zirconia restorations. They reported the following retentive values: 203.49 N for 5.5-mm abutments and 230.37 N for 3-mm-tall abutments. This is considerably lower than the results obtained in the present study. For example, G-CEM LinkAce (GC Corp) cement reached 1338 N before airborne-particle abrasion and 662 N after the airborne-particle abrasion of the titanium bases. These differences can be explained by the fact that Nejatidanesh et al[19,27] used traditional titanium abutments for crown cementation, whereas titanium bases with an additional mechanical interlocking were used in the present study.

Only a few studies have focused on the retention of zirconia copings over titanium bases.[28,29] Gehrke at al[28] reported the mean retentive strength to be from 650.77 ±74.92 to 924.93 ±3.31 N for different resin cements. These values are also considerably higher than the retention of zirconia copings on prosthetic abutments, which demonstrates that titanium bases offer substantially improved retention of zirconia suprastructures. von Maltzahn et al[29] investigated the retention of zirconia copings on airborne-particle-abraded titanium bases using 2 different resin cements and reported the mean values to be from 223.3 ±67.6 N to 598.6 ±173.7 N. These values are consistent with those of the present study, which showed lower retention values on airborne-particle-abraded titanium bases than those on new titanium bases.

As the present study showed statistically significant differences between the mechanical surface treatments of titanium bases, the null hypothesis stating that airborne-particle abrasion of titanium bases does not improve retention of zirconia copings was rejected. However, airborne-particle abrasion with 50-μm $Al_2O_3$ particles did not improve but significantly reduced the retention of zirconia copings with all the tested luting agents ($P<.05$).

When a material is abraded with airborne particles, it is affected by particles of different grain sizes. In general, airborne-particle abrasion increases the surface area and creates higher surface roughness. The cement can optimally wet the larger interface, resulting in better mechanical retention of the restoration.[34] Different results regarding the effect of airborne-particle abrasion have been reported. Some studies have reported that rough airborne-particle-abraded titanium copings provided greater micromechanical retention than the smooth machined titanium abutment surface.[16] In contrast, the present study produced evidence for a decrease in the retentive strength of zirconia copings on airborne-particle-abraded titanium bases. This is an unexpected finding because logically an increased surface would lead to increased retention strength. However, the results of the present study agree with the findings of Nejatidanesh et al,[21] who concluded that airborne-particle abrasion did not improve the retention of base metal alloy copings over titanium abutments. Different explanations can be provided to clarify the outcome of the study. After airborne-particle abrasion, some of the particles of the abrasion material can stay inside the metal and reduce the bonding between the titanium base and the zirconia coping.

Papadopoulos et al[35] reported the presence of loose alumina on the titanium porcelain interface, which is attributed mainly to the airborne-particle abrasion procedure. The analysis of the microstructure and roughness of the cast, commercially pure titanium surface showed that alumina particles were embedded in the surface layer of titanium regardless of the particle size of the 3 different alumina powders. The use of large particle alumina seemed advantageous in reducing the alumina remaining on the titanium surface while also increasing the surface roughness. Papadopoulos et al[35] further discussed how loose alumina particles remained on the surface layer of metal and weakened the bonding strength between titanium and porcelain and how those loose particles could not be removed even by ultrasonic cleaning. Swartz et al[34] also reported the absence of an increase in retention when implant-supported prostheses were cemented with resin-modified glass ionomer after airborne-particle abrasion.

Another possible reason could be the change in the microgeometry of the titanium base and the cement gap. After abrasion, the retentive grooves present on a titanium base may be dulled and the cement space increased, which in turn might reduce the dislodging force. The manufacturers of the Ceka Site (CEKA PRECI-LINE) cement recommend airborne-particle abrasion of the bonding surfaces before cement application. This can be explained by the fact that a primary indication for the use of this cement is the bonding of metal precision attachments for removable partial dentures. The statistical analysis showed that the G-CEM LinkAce (GC Co) dislodgment force was further reduced compared with that of the other tested cements. This cement may be more sensitive to the status of the titanium base than other bonding agents. Despite the drop in retention strength, how much retentiveness is needed for a crown to be retentive on the titanium base is still not clear; even with reduced strength, zirconia copings may be able to withstand occlusal forces without decementation.

A limitation of this study was that the same zirconia copings and titanium bases were used in both stages of the experiment. Dislodging of the copings and airborne-particle abrasion could influence the changes in the bonding surfaces and lead to a lower retention force. Perhaps some flaws might have been introduced into the zirconia during the first part of the experiment, leading to the presented results. However, the present study is not the first to report that airborne-particle abrasion can give opposite results to those expected.[7,21,31-35]

Future experiments should focus on assessing the retention strength of newly introduced cements. In addition, clinical studies are needed to determine whether the results of the present in vitro experiments are clinically valid.

## CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The brand of resin cement significantly increased the retention of the zirconia coping over smooth and airborne-particle-abraded titanium bases.
2. Airborne-particle abrasion of titanium bases decreased the retentive strength of zirconia copings cemented with a resin luting agent.

## REFERENCES

1. Gehrke P, Johannson D, Fischer C, Stawarczyk B, Beuer F. In vitro fatigue and fracture resistance of one- and two-piece CAD/CAM zirconia implant abutments. Int J Oral Maxillofac Implants 2015;30:546-54.
2. Leutert CR, Stawarczyk B, Truninger TC, Hämmerle CH, Sailer I. Bending moments and types of failure of zirconia and titanium abutments with internal implant-abutment connections: a laboratory study. Int J Oral Maxillofac Implants 2012;27:505-12.
3. Truninger TC, Stawarczyk B, Leutert CR, Sailer TR, Hämmerle CH, Sailer I. Bending moments of zirconia and titanium abutments with internal and external implant-abutment connections after aging and chewing simulation. Clin Oral Implants Res 2012;23:12-8.
4. Sailer I, Sailer T, Stawarczyk B, Jung RE, Hämmerle CH. In vitro study of the influence of the type of connection on the fracture load of zirconia abutments with internal and external implant-abutment connections. Int J Oral Maxillofac Implants 2009;24:850-8.
5. Gigandet M, Bigolin G, Faoro F, Bürgin W, Brägger U. Implants with original and non-original abutment connections. Clin Implant Dent Relat Res 2014;16:303-11.

6. Covey DA, Kent DK, St Germain HA Jr, Koka S. Effects of abutment size and luting cement type on the uniaxial retention force of implant-supported crowns. J Prosthet Dent 2000;83:344-8.
7. Al Hamad KQ, Al Rashdan BA, Abu-Sitta EH. The effects of height and surface roughness of abutments and the type of cement on bond strength of cement-retained implant restorations. Clin Oral Implants Res 2011;22:638-44.
8. Saleh Saber F, Abolfazli N, Nuroloyuni S, Khodabakhsh S, Bahrami M, Nahidi R, et al. Effect of abutment height on retention of single cement-retained, wide- and narrow-platform Implant-supported restorations. J Dent Res Dent Clin Dent Prospects 2012;6:98-102.
9. Abbo B, Razzoog ME, Vivas J, Sierraalta M. Resistance to dislodgement of zirconia copings cemented onto titanium abutments of different heights. J Prosthet Dent 2008;99:25-9.
10. Bresciano M, Schierano G, Manzella C, Screti A, Bignardi C, Preti G. Retention of luting agents on implant abutments of different height and taper. Clin Oral Implants Res 2005;16:594-8.
11. Gultekin P, Gultekin BA, Aydin M, Yalcin S. Cement selection for implant-supported crowns fabricated with different luting space settings. J Prosthodont 2013;22:112-9.
12. Dudley JE, Richards LC, Abbott JR. Retention of cast crown copings cemented to implant abutments. Aust Dent J 2008;53:332-9.
13. Güler U, Budak Y, Queiroz JRC, Özcan M. Dislodgement resistance of zirconia copings cemented onto zirconia and titanium abutments. Implant Dent 2017;26:510-5.
14. Tanış MÇ, Akay C, Karakış D. Resin cementation of zirconia ceramics with different bonding agents. Biotechnol Biotechnol Equip 2015;29:363-7.
15. Yoshida K, Tsuo Y, Atsuta M. Bonding of dual-cured resin cement to zirconia ceramic using phosphate acid ester monomer and zirconate coupler. J Biomed Mater Res B Appl Biomater 2006;77:28-33.
16. Garg P, Pujari M, Prithviraj DR, Khare S. Retentiveness of various luting agents used with implant-supported prosthesis: an in vitro study. J Oral Implantol 2014;40:649-54.
17. Uludamar A, Ozkan Y, Ozkan YK. Effects of thermocycling on the retention of various cements of one-unit and three-unit fixed implant-supported restorations. Int J Oral Maxillofac Implants 2012;27:567-76.
18. Carnaggio TV, Conrad R, Engelmeier RL, Gerngross P, Paravina R, Perezous L, et al. Retention of CAD/CAM all-ceramic crowns on prefabricated implant abutments: an in vitro comparative study of luting agents and abutment surface area. J Prosthodont 2012;21:523-8.
19. Nejatidanesh F, Savabi O, Jabbari E. Effect of surface treatment on the retention of implant-supported zirconia restorations over short abutments. J Prosthet Dent 2014;112:38-44.
20. 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;31:555-62.
21. Nejatidanesh F, Savabi O, Ebrahimi M, Savabi G. Retentive strength of implant-supported base metal copings over short metal abutments using different luting agents and surface treatments. Implant Dent 2014;23:162-7.
22. Assenza B, Scarano A, Leghissa G, Carusi G, Thams U, Roman FS, et al. Screw- vs cement-retained implant restorations: an experimental study in the beagle. Part 1. Screw and abutment loosening. J Oral Implantol 2005;31:242-6.
23. Qeblawi DM, Munoz CA, Brewer JD, Monaco EA Jr. The effect of zirconia surface treatment on flexural strength and shear bond strength to a resin cement. J Prosthet Dent 2010;103:210-20.
24. Ferracane JL, Stansbury JW, Burke FJ. Self-adhesive resin cements - chemistry, properties and clinical considerations. J Oral Rehabil 2011;38:295-314.
25. Senilmaz DP, Palin WM, Shortall ACC, Burke FJT. The effect of surface preparation and luting agent on bond strength to a zirconium-based ceramic. Oper Dent 2007;32:623-30.
26. Lee SE, Bae JH, Choi JW, Jeon YC, Jeong CM, Yoon MJ, et al. Comparative shear-bond strength of six dental self-adhesive resin cements to zirconia. Materials 2015;8:3306-15.
27. Nejatidanesh F, Savabi O, Shahtoosi M. Retention of implant-supported zirconium oxide ceramic restorations using different luting agents. Clin Oral Implants Res 2013;24:20-4.
28. Gehrke P, Alius J, Fischer C, Erdelt KJ, Beuer F. Retentive strength of two-piece CAD/CAM zirconia implant abutments. Clin Implant Dent Relat Res 2014;16:920-5.
29. von Maltzahn NF, Holstermann J, Kohorst P. Retention forces between titanium and zirconia components of two-part implant abutments with different techniques of surface modification. Clin Implant Dent Relat Res 2016;18:735-44.
30. Rismanchian M, Davoudi A, Shadmehr E. Effect of using nano and micro airborne abrasive particles on bond strength of implant abutment to prosthesis. Braz Dent J 2015;26:50-5.
31. Abreu A, Loza MA, Elias A, Mukhopadhyay S, Looney S, Rueggeberg FA. Tensile bond strength of an adhesive resin cement to different alloys having various surface treatments. J Prosthet Dent 2009;101:107-18.
32. Abreu A, Loza MA, Elias A, Mukhopadhyay S, Rueggeberg FA. Effect of metal type and surface treatment on in vitro tensile strength of copings cemented to minimally retentive preparations. J Prosthet Dent 2007;98:199-207.
33. Wolfart M, Wolfart S, Kern M. Retention forces and seating discrepancies of implant-retained castings after cementation. Int J Oral Maxillofac Implants 2006;21:519-25.
34. Swartz JM, Davis RD, Overton JD. Tensile bond strength of resin-modified glass-ionomer cement to microabraded and silica-coated or tin-plated high noble ceramic alloy. J Prosthodont 2000;9:195-200.
35. Papadopoulos T, Tsetsekou A, Eliades G. Effect of aluminium oxide sandblasting on cast commercially pure titanium surfaces. Eur J Prosthodont Restor Dent 1999;7:15-21.



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