THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Retentive strength of implant-supported CAD-CAM lithium disilicate crowns on zirconia custom abutments using 6 different cements

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ABSTRACT

Statement of problem. The optimal retention of implant-supported ceramic crowns on zirconia abutments is a goal of prosthodontic treatment.

Purpose. The purpose of this in vitro study was to evaluate the retentive strength of implant-supported IPS e.max CAD-CAM (e.max) crowns bonded to custom zirconia implant abutments with different cements.

Material and methods. An optical scan of a zirconia custom abutment and a complete-coverage modified crown was designed using an intraoral E4D scanner. One hundred twenty lithium disilicate crowns (IPS e.max CAD) were cemented to 120 zirconia abutment replicas with 1 of 6 cements: Panavia 21 (P21), Multilink Hybrid Abutment (MHA), RelyX Unicem 2 (RXU), RelyX Luting Plus (RLP), Ketac Cem (KC), and Premier Implant (PI). The specimens were stored at 37°C in 100% humidity for 24 hours. Half of the specimens were thermocycled for 500 cycles. The retentive force was measured using a pull-out test with a universal testing machine. Mean retentive strengths (MRS) were calculated using 2-way ANOVA and the Tukey-Kramer test (α=.05).

Results. The MRS (MPa) after 24-hour storage were P21 (3.1), MHA (2.5), RXU (2.5), RLP (1.3), KC (0.9), and PI (0.5). The MRS after thermocycling were MHA (2.5), P21 (2.2), RLP (1.8), KC (1.4), RXU (1.1), and PI (0.3). P21 had the highest MRS after 24-hour storage (P<.001), but after thermocycling MHA had the highest MRS (P<.001). RXU showed a significant decrease in MRS after thermocycling (P<.05). Cement residue was mostly retained on the zirconia abutments for P21, while for the other cements' residue was retained on the lithium disilicate crowns.

Conclusions. The cements tested presented a range of retentive strengths, providing the clinician with a choice of more or less retentive cements. MHA was the most retentive cement after thermocycling. Thermocycling significantly affected the retentive strengths of the P21 and RXU cements. (J Prosthet Dent 2017;117:247-252)

Implant dentistry is continually advancing. Although titanium abutments have been used for many years, one of their shortcomings is metal show-through with anterior esthetic implant restorations on thin gingival biotypes.[1] Zirconia implant abutments have proven to be a good alternative to titanium and allow for improved gingival appearance.[2] The retention of the different types of cement that should be used to bond lithium disilicate crowns to zirconia abutments has not been well described. Much has been published on the bonding of crowns to titanium abutments but not to zirconia abutments.[3-6]

Two types of implant prostheses are commonly used: screw-retained and cement-retained. Screw-retained implant prostheses allow for retrievability and provide restorations in decreased interocclusal space.[7,8] Cement-retained implant prostheses provide improved esthetics because of the absence of a screw-access hole, the ability to use angled custom abutments, and improved passive fit.[7-9]

Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) abutments are popular because of their improved esthetics and superior mechanical properties

Supported, in part, by The Greater New York Academy of Prosthodontics and Ivoclar Vivadent. Dr Shashi Singhal, Ivoclar Vivadent, provided IPS e.max blocks, zirconia abutments, and Multilink Hybrid Abutment cement; and contributed to project design. Premier Dental donated Premier Implant cement.
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Clinical Implications

When lithium disilicate crowns are cemented on zirconia implant abutments, the highest retention after thermocycling is achieved with Multilink Hybrid Abutment cement.

compared with other ceramic materials.[10] Y-TZP was found to have a lifetime (20 years) similar to that of metal ceramic fixed dental prostheses when subjected to cyclic fatigue in water.[11]

Traditional cements can be used to provide mechanical retention for zirconia restorations.[12] However, because zirconia is not acid-etchable, bonding with resin is possible if a conditioning treatment is used. Y-TZP can be airborne-particle abraded with 50 μm alumina for 10 to 15 seconds or airborne-particle abraded with silica-coated alumina particles and silanated.[13] An acidic adhesive monomer can also be used to bond zirconia to resin cement.[14] The phosphate ester group of the monomer bonds to metal oxides, allowing the resin to bond when polymerized.

Retention as defined by the glossary of prosthodontic terms is the "quality inherent in the dental prosthesis acting to resist the forces of dislodgment along the path of placement."[15] Cast restorations cemented to titanium abutments progress in the following order of retention when subjected to a tensile test: interim cement < glass ionomer cement < zinc phosphate cement < resin-modified glass ionomer cement < resin cement.[3-5,16] Polycarboxylate cement interacts with titanium and is contraindicated for titanium abutments.[17] Zirconia computer-aided design (CAD) copings cemented to titanium abutments with interim cement showed greater retention with greater abutment height.[4]

Zirconia copings cemented to zirconia abutments with different interim cements showed no significant difference in retention when subjected to tensile testing.[18] ProCAD leucite (Ivoclar Vivadent AG) glass ceramic CAD copings cemented to titanium abutments of different surface areas showed that surface area made little difference when adhesive-resin cements were compared during tensile testing.[6] However, increased surface area showed greater retention when interim cement or resin-modified glass ionomer cement was used.[6]

Many studies have investigated bonding to zirconia. When composite resin cylinders were bonded to zirconia blocks with Multilink resin cement (Ivoclar Vivadent AG), thermocycling significantly decreased bond strength.[19] The use of Monobond Plus (Ivoclar Vivadent AG) significantly increased bond strength, and ultrasonic cleaning had no effect on bond strength. When zirconia was bonded with an adhesive phosphate monomer cement, the bond strength was higher than with other cements.[20-23] After thermocycling, more adhesive failures occurred than after no thermocycling.[20] Therefore, thermocycling appears to be a better test for evaluating the durability of zirconia bond strength. When bonded to zirconia, resin cements decreased significantly in bond strength after thermocycling.[24-26]

Lithium disilicate is an esthetic ceramic material with high strength that can be bonded to tooth structure.[27,28] Two adhesive procedures can be used for bonding lithium disilicate restorations.[29] Mechanical adhesion can be used after airborne-particle abrasion with 50-μm aluminum oxide or acid etching with hydrofluoric acid and the application of silane primer. Acid etching dissolves the glassy phase, and silane allows chemical bonds to form between the organic component of the resin cement and the inorganic component of the ceramic.[13,29]

Pressed lithium disilicate showed better shear bond strength when it was treated with hydrofluoric acid and silane primer before bonding with resin cement.[30,31] Bond strength decreased after thermocycling.[30] Lithium disilicate surfaces treated with hydrofluoric acid and airborne-particle abrasion had better bond strengths than lithium disilicate treated with either hydrofluoric acid or airborne-particle abrasion alone.[32,33]

CAD-CAM lithium disilicate decreased in flexural strength when the pressure used for airborne-particle abrasion was above 100 kPa.[34] Lithium disilicate crowns, when treated with hydrofluoric acid and cemented with Multilink Implant cement (Ivoclar Vivadent AG), showed a higher fracture load than leucite and zirconia crowns cemented to zirconia abutments.[35] Thermocycling and artificial aging had no significant effect on fracture load. Overall, the shear bond strength of resin cements to lithium disilicate decreased after thermocycling.[36] However, one study showed that bond strength increased after 1000 cycles when resin cement was bonded to lithium disilicate.[37]

The purpose of this research was to evaluate the tensile retentive strength of implant-supported lithium disilicate crowns bonded to zirconia implant abutments with 6 different cements. The null hypotheses were that no difference in retentive strength would be found among the 6 tested cements and that thermocycling would not affect the retentive strength of the cements.

MATERIAL AND METHODS

An optical scan was made with an intraoral scanner (E4D Dentist; Planmeca) of a zirconia implant custom abutment replica that had been modified from a patient's custom premolar implant abutment (Atlantis; Dentsply Intl). A total of 120 custom zirconia implant abutment replicas (Wieland Zenotec ZR Bridge; Ivoclar Vivadent

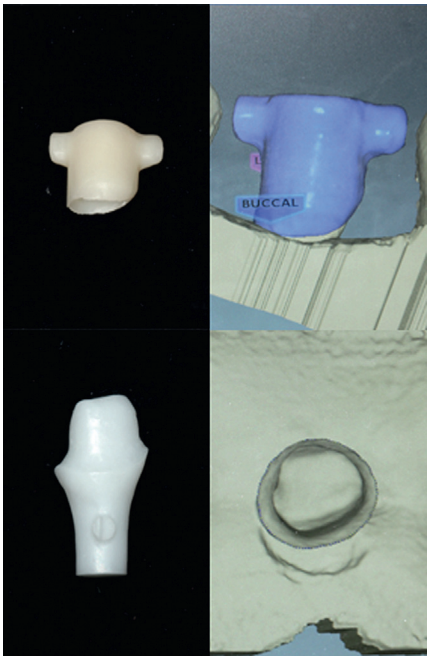

Figure 1. Complete-coverage modified crown and zirconia custom implant abutment replica. Optical scan of crown and abutment with E4D intraoral scanner.

AG) were milled. A wax pattern of a complete-coverage modified crown was carved and designed to have marginal fit to the custom zirconia implant abutment replica. The occlusal surface of the wax pattern was extended laterally to create handles held by a brass device (Fig. 1). The completed wax pattern of the modified crown was then scanned with an E4D intraoral scanner. One hundred twenty lithium disilicate crowns were then milled from IPS e.max CAD blocks (Ivoclar Vivadent AG) using a CAD-CAM milling machine (PlanMill 40; Planmeca USA). All 120 custom zirconia implant abutment replicas were embedded into a polyvinyl chloride ring (Schedule PVC Reducer Bushing; Dura) filled with autopolymerizing acrylic resin (SamplKwick; Buehler) with a dental surveyor (Fig. 2). The internal surface of the crowns was treated with 50-μm aluminum oxide at 100 kPa, steam cleaned, and dried with oil-free air. This was followed by treatment with 5% hydrofluoric acid gel (Ivoclar Vivadent AG) for 20 seconds, after which the crowns were again steam cleaned and dried with oil-free air.

Six different cements were tested: Panavia 21 (P21), Multilink Hybrid Abutment (MHA), RelyX Unicem 2 (RXU), RelyX Luting (RXL), Ketac Cem (KC), and Premier Implant (PI) (Table 1). The crowns to be cemented with MHA and RXU were treated with a coupling agent (Monobond Plus; Ivoclar Vivadent AG) for 60 seconds. The crowns cemented with P21 were treated with a silane coupling agent (Clearfil Ceramic Primer; Kuraray America) for 60 seconds. The zirconia abutments in the MHA, RXU, and P21 cement groups were treated with

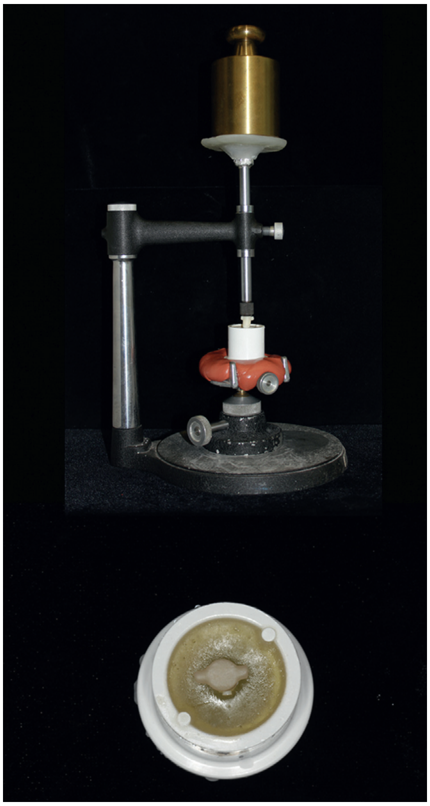

Figure 2. Custom zirconia implant abutment replica embedded in acrylic resin using surveyor. Finger pressure was used to seat crowns and 20-N axial load placed for 10 minutes.

Table 1. Type, code, and manufacturer of cements tested

Cement (Code)	Manufacturer	Cement Type
Premier Implant (PI)	Premier Dental	Resin provisional cement
Ketac Cem (KC)	3M ESPE	Glass ionomer cement
RelyX Luting Plus (RLP)	3M ESPE	Resin-modified glass ionomer cement
RelyX Unicem 2 (RXU)	3M ESPE	Self-adhesive resin cement
Multilink Hybrid Abutment (MHA)	Ivoclar Vivadent AG	Adhesive resin cement
Panavia 21 (P21)	Kuraray America	Adhesive resin cement

Monobond Plus (Ivoclar Vivadent AG). For all other groups, the zirconia abutments were not treated.

Ten specimens were allocated to 12 experimental groups. Half (6 cements×10 specimens=60 specimens) were stored for 24 hours, and the other half were stored for 24 hours and then subjected to thermocycling. The abutments were steam cleaned and dried with oil-free air before cementation. For each cement, the crowns were bonded to the abutments according to the manufacturer's instructions. The crowns were initially seated with finger pressure. Then, a 20-N load was directed axially onto the cemented crowns for 10 minutes (Fig. 2). Excess interim cement and glass ionomer cement were removed with a scaler, and excess resin cement with rubber points. The

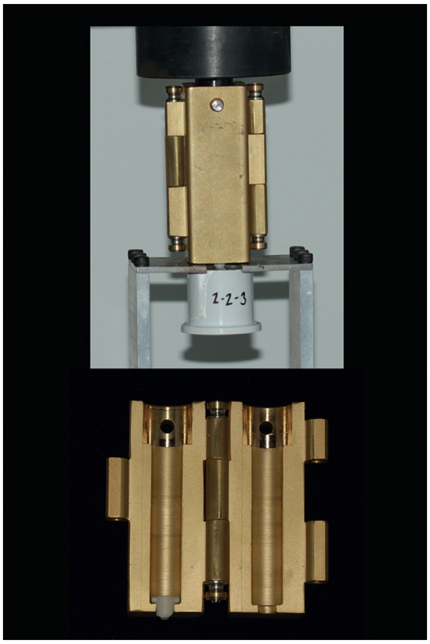

Figure 3. Experimental design with custom device to hold crowns in universal testing machine.

specimens were stored at 37°C in 100% humidity for 24 hours. Half of the specimens were thermocycled for 500 cycles according to the ISO/TS 11405 standard for intermediate aging protocol.[38] The retentive force was measured by using a pull-out test with a universal testing machine (Instron Universal Testing Machine Model 8501; Instron Corp) set at a 0.5 mm/min crosshead speed (Fig. 3).

The mean retentive force required to debond the specimens was recorded in newtons. This was converted to MPa using the surface area of 86.5 mm^2 for retentive strength. The surface area of the abutment was calculated by using the surface area of a cylinder, ($A=2\pi r^2+2\pi rh$), where r is the radius, h is the height, and $\pi=3.14$, and then subtracting the area because the abutment has only one end ($A=\pi r^2+2\pi rh$). Average height and radius measurements were used as the abutment was custom.

Mean retentive strength was analyzed statistically using 2-way analysis of variance (ANOVA). The Tukey-Kramer test was performed to identify any statistically significant differences among the cement groups and between the conditions of 24-hour storage and thermocycling (α=.05). The failure mode of the cement was also scored to indicate whether cement remained on the crown or on the abutment when the crowns were debonded. A light microscope was used to evaluate the debonded surface to determine the mode of failure as adhesive or cohesive and on which surface the cement remained (Fig. 4).

RESULTS

Mean retentive strength and standard deviations are listed in Table 2. Means with the same superscripted letters were

Figure 4. Representative image of debonded surface showed cement residue left on lithium disilicate crown.

Table 2. Mean (SD) of retentive strength (MPa)

Cement	24 h	Thermocycled
P21	3.1 (0.8)	2.2 (0.4)^{de}
MLH	2.5 (0.8)^{ah}	2.5 (0.8)^{dh}
RXU	2.5 (1.0)^{a}	1.1 (0.4)^{g}
RXL	1.3 (0.6)^{bi}	1.8 (0.5)^{efi}
KC	0.9 (0.2)^{bcj}	1.4 (0.3)^{fgj}
PI	0.5 (0.2)^{ck}	0.3 (0.1)^{k}

ANOVA showed significant differences between conditions (P=.02) and among cements (P<.001) with significant interactions (P<.001). Tukey-Kramer test intervals for comparisons of means between conditions and among cements were 0.2 and 0.5 MPa at .05 level of significance. Means with same superscript letters not statistically different (P>.05).

not statistically different. Mean retentive strength for the 24-hour storage group ranged from 0.5 to 3.1 MPa. Mean retentive strength for the thermocycled group ranged from 0.3 to 2.5 MPa. Retentive strengths for 24-hour storage were in decreasing order as follows: P21 > MHA = RXU > RLP > KC > PI. The retentive strengths of the thermocycled specimens were in decreasing order as follows: MHA > P21 > RLP > KC > RXU > PI.

A 2-way ANOVA showed significant main effects for the cements and conditions of 24-hour storage compared with thermocycling with significant interactions (Table 3). The Tukey-Kramer intervals (α=.05) for comparing the means of retentive strength (MPa) among the cements were 0.5 MPa and 0.2 MPa between the conditions. P21 had the highest retentive strength after 24-hour storage, but MHA had the highest retentive strength after thermocycling. Of the 3 resin cements, RXU had a significant drop in retentive strength after thermocycling (2.5 MPa to 1.1 MPa). Thermocycling did not significantly affect the retentive strengths of the KC, MHA, PI, or RLP cements.

Table 3. Analysis of variance (ANOVA) of retentive strength (MPa)

Source	df	Sum of Squares	Mean Square	F	P	Lambda	Power
Conditions	1	1.865	1.865	5.481	.021	5.481	0.638
Cements	5	73.92	14.784	43.458	<.001	217.291	1
Conditions×Cements	5	15.23	3.046	8.954	<.001	44.771	1
Residual	108	36.74	0.34				

All modes of failure were adhesive in nature. Cement residue was found mostly on the zirconia implant abutments for P21, while the remaining 5 cements had cement residue on the lithium disilicate crowns. Some of the crowns fractured during testing in the P21 and MHA cement groups.

DISCUSSION

This study focused on cement-retained implant restorations using zirconia esthetic abutments and IPS e.max crowns. The goal of this study was to offer clinicians a range of the retentiveness of cements to be used when cementing lithium disilicate crowns to zirconia abutments. The resin cements tested (P21, MHA, and RXU) performed better than the other cements (RLP, KC, and PI) after 24-hour storage. The increased retentive strength of the resin cements is most likely due to its ability to bond to the lithium disilicate.[37] Hydrofluoric acid dissolves the glassy phase of the lithium disilicate and creates surface irregularities that can increase the surface area for bonding. A silane coupling agent was added to the lithium disilicate surface, allowing chemical bonds to form between the organic component of the resin cement and the inorganic component of the ceramic.[13]

In one study, when glass ionomer, resin-modified glass ionomer, and resin cements were bonded to lithium disilicate pretreated with hydrofluoric acid and silane, only resin cements showed high bond strengths after 1000 thermocycles.[37] Similar findings were evident in this study. The resin cements in this study showed better retentive strength after 500 thermocycles compared with the other cements tested. The 2 resin cements performed better than the self-adhesive resin cement after thermocycling. The increased retentive strength may be due to the phosphate ester group of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) in P21 cement bonding directly to zirconia oxide. The Monobond plus that was applied to zirconia abutments of resin specimens also contains MDP that could have increased retention.[14] RXU does not contain MDP, which may explain the decrease in retentive strength compared with the other cements.

Because this study was the first to test retentive strength of lithium disilicate to zirconia, comparing the findings to similar studies is impossible. Therefore, comparing this study to others that tested bond strength would be indicated. Lüthy et al[22] found similar results using P21, which performed better than Panavia F, Unicem, and Super C & B when bonded to zirconia and a stainless steel cylinder and thermocycled. Seto et al[24] found that Panavia F 2.0 had the highest overall bond strength to zirconia after thermocycling when compared with other resin cements, including Multilink, Unicem, and G-Cem. In the same study, Unicem had a significant drop in shear bond strength after 100 thermocycles compared with the other resin cements. This study is consistent with P21 having high bond strength to zirconia and RXU having greatly reduced bond strength to zirconia after thermocycling.

All pull-out tests resulted in adhesive failures. However, P21 cement residue was retained mostly on the zirconia abutment, while the other cement residues were retained on the lithium disilicate crowns. This may be because the phosphate ester group of MDP contained in P21 bonded to the zirconia.[14] All other tested cements remained on the lithium disilicate crowns because of the etchable ceramic and silane-treated surface mentioned earlier. Seto et al[24] also found that during shear bond testing, Panavia cement residue was mostly found on zirconia, while other resin cements were found on the composite resin rod. Crown fractures were observed in some of the P21 and MHA groups. This may be due to the higher retentive strengths of these cements and the phosphate ester group of MDP contained in the cement directly bonding to the zirconia oxide forcing the crown to fracture before the bond could be broken.[14]

KC and RLP showed increased retentive strength after thermocycling. This can be explained by the increase in crosslinking upon complete setting. The heat from a hot water bath can aid in the polymerization of cements.[24] Also glass ionomer cements can continue to set over time.[39] Glass ionomer cements can take several months to reach their complete setting reaction. If there had been more than 500 thermocycles, the bond strength may have decreased after the glass ionomer cements had reached full set.

Many studies have analyzed the shear bond strength of resin cements to zirconia after thermocycling. Even though shear bond strength is different from retentive strength, similar trends are still evident. Resin cements have a significant decrease in bond strength after thermocycling when bonded to zirconia.[24-26] Overall, resin cements decrease in shear bond strength to lithium disilicate after thermocycling.[36] In contrast, Nagai et al[30] found that Unicem and Variolink II increased in shear bond strength after thermocycling. In the present study, MHA did not increase in retentive strength, but it also did not decrease. The retentive strength remained the same after thermocycling (2.5 MPa), which would be advantageous in vitro. P21 decreased from 3.1 to 2.2 MPa but is still a good clinical option. RXU decreased from 2.5 to 1.1 MPa and may be less preferable if high retentive strength is needed.

Generally, bonding to zirconia is more difficult than bonding to lithium disilicate because of the nature of the ceramic. Lithium disilicate can be etched and silanated, whereas zirconia cannot be etched and has no bonding capabilities unless it is pretreated with an adhesive phosphate monomer. Many studies have tested the bond strength of cement to zirconia or lithium disilicate and these materials bonded to tooth structure, but none have attempted to bond the 2 materials together. This study aimed to bond zirconia to lithium disilicate, simulating a zirconia abutment and lithium disilicate crown and testing retentive strength to determine the best cement to use in this clinical situation.

In summary, the retentive strength of MHA showed the highest retentive strength after thermocycling, followed by P21. P21 showed more affinity for bonding to zirconia than lithium disilicate. Clinicians should consider using MHA or P21 cement if high retention is required and RLP or KC if medium retention is required. PI would be indicated for temporary cementation. Further research could focus on treating the zirconia abutment surface with aluminum oxide or an adhesive phosphate monomer. Also long-term aging studies could be conducted to test the retentive strength of the cements.

CONCLUSIONS

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

1. Of the 6 cements tested, MHA was the most retentive after thermocycling.
2. The least retentive cement was PI.
3. Thermocycling significantly affected the retentive strengths of the P21 and RXU cements.

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Acknowledgments
The authors thank Mr Pat Barnett, a machinist at the MD Anderson Cancer Center, for fabricating a device to be used on the universal testing machine.