Influence of cyclic loading on load-to-failure of different ceramic CAD-CAM implant-supported single crowns

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ABSTRACT

Purpose: To compare the load to failure values of different ceramic CAD/CAM implant crown materials with drilled screw access holes with and without cyclic loading applied. Materials and Methods: Forty zirconia abutments with a titanium base were pre-loaded onto implants to support maxillary right first premolar crowns that were milled from four different CAD/CAM ceramic materials (zirconia reinforced lithium silicate, hybrid ceramic, lithium disilicate, and zirconia; n = 10 each). After cementing the crowns, screw access channels were prepared by drilling through occlusal surfaces. Half of the specimens were subjected to cyclic loading for 5 million cycles at 2 Hz (n = 5/material). After cyclic loading, vertical loads were applied to failure, and the load to failure values of all crowns were recorded and statistically analyzed. Two-way analysis of variance was used with restricted maximum likelihood estimation and Tukey-Kramer adjustments (α = .05). Results: During cyclic loading, the zirconia abutment in one lithium disilicate specimen cracked at 2 million cycles, as well as a zirconia-reinforced lithium silicate crown. Results for the load to failure test series showed statistical differences between the materials. Zirconia resulted in significantly higher failure loads when compared to the other materials (P < .001). Cyclic loading did not significantly affect the load to failure
values. **Conclusion:** Cyclic loading did not significantly influence the load to failure of any of the materials tested. Zirconia crowns with drilled screw access channels cemented on zirconia abutments with a titanium base had higher load to failure values compared to the other ceramic crown materials. *Int J Prosthodont* 2021. doi: 10.11607/ijp.6510

**INTRODUCTION**

Cement-retained implant prostheses have been advocated when esthetics are paramount or when implants are not ideally placed.\(^1\)\(^-\)\(^5\) Furthermore, the implant crowns, as well as occlusal contacts, may be more stable due to the absence of a screw access channel.\(^6\)\(^,\)\(^7\) A major concern with cement-retained implant prostheses is the difficulty when removing them to address abutment screw loosening or other implant-related complications.\(^1\) When the screw access opening location is unknown, the removal of cement-retained crowns with abutment screw loosening or ceramic fracture is challenging without causing irreversible damage to the crown or abutment. Any force applied to remove the prosthesis can damage the inner surface of the implant or break the screw connection to the abutment.\(^5\)\(^,\)\(^8\) Several authors have sought to add a retrieval feature to cemented prostheses to facilitate easier removal.\(^5\)\(^-\)\(^11\) Various methods have been described to facilitate removal, including the use of interim cement,\(^12\) marking the location of the screw access channel on the occlusal surface and securing the crown to the abutment with a small lingual screw,\(^13\) a combined cement-screw retained restoration,\(^14\) using digital photographs\(^15\) or a CAD/CAM generated drilling guide based on the master casts with inserted implant analogs.\(^9\) Rajan et al\(^5\) and Uludag et al\(^11\) have proposed an access channel on cement-retained implant crowns. Bond strength tests showed that screw access did not impair crown retention. Results showed no significant difference to conventional cement-retained crowns.
One concern with that technique is whether creating a screw access channel in a cement-retained crown would significantly influence the fracture resistance of the crown material. Previous studies reported varying outcomes when conventional materials were tested. Obermeier et al.\textsuperscript{4} evaluated the fracture resistance of screw-retained and cement-retained all-ceramic crowns. The authors reported no significant difference between the two groups. However, different types of failure patterns among the applied all-ceramic materials were noted. Torrado et al.\textsuperscript{7} found that significantly less force was needed to fracture screw-retained metal-ceramic crowns than cemented crowns. There are studies showing that recently introduced CAD-CAM monolithic crown materials may be less susceptible to grinding damage compared to traditionally utilized materials like lithium disilicate or zirconia.\textsuperscript{16,17} However, these materials haven’t been evaluated for their performance under loads when a screw access channel is manually prepared on a cement-retained crown to make the cement-retained crown retrievable when the abutment screw is loose, which is one of the methods used to access the loose screw.

The aim of this study was to measure and compare the load required to fracture ceramic CAD-CAM crown materials (zirconia reinforced lithium-silicate, hybrid ceramic, lithium disilicate, zirconia) after a screw access channel was created and sealed with a light-polymerized composite resin. The effect of cyclic loading on the load-to-failure of crowns was also aimed to be investigated. The first null hypothesis was that the crown material would not affect the load-to-failure values. The second null hypothesis was that the cyclic loading would not affect the load-to-failure values.
MATERIALS and METHODS

For the cyclic loading tests, 40 implants (3.7 mm D X 10 mm 3.5 mm Platform Legacy 1; Implant Direct) were embedded and bonded in a bone substitute material (G10, McMaster Carr) using a composite resin (Rock Core, Danville Materials), which has similar elasticity to cancellous bone. The implant sites were prepared by using a surgical implant handpiece, which was compatible with the implant system (Surgical Motor System, Zimmer Dental). The implants were embedded in the bone substitute leaving the coronal 3 mm of the implant exposed. Forty prefabricated zirconia abutments with titanium bases (Ti-bases) (Legacy Zirconia Straight Contoured Abutment, 3.5mmD/1mm Collar Height; Implant Direct) were then screwed to the implants and screws were torqued to establish manufacturer-recommended preload (30 Ncm) using a torque wrench. Two cotton pellets size #1 (Richmond Dental Inc.) were placed on the screw heads and a single component composite resin (Telio CS Inlay; Ivoclar Vivadent) was packed and photopolymerized for 30 seconds to seal the screw access channel.

Digital impressions of prefabricated abutments were taken with a laboratory scanner (D800; 3Shape) according to the manufacturer’s recommendations. After scanning, the final data sets were transferred to a dental laboratory for crowns to be designed virtually as a first maxillary premolar (Fig. 1). Four different crown materials; zirconia reinforced lithium-silicate (ZLS), hybrid ceramic (HC), lithium disilicate (LDS), and zirconia (ZIR) were used for the fabrication of implant-supported crowns. The crown design included a 4 mm diameter indentation for the force applicator tip in the central groove to equalize the force (Fig. 2). A detailed overview of the applied materials is given in Table 1 (Tab.1). Ten right 1st premolar crowns for each material were fabricated. For standardization, all crowns had the same digital design (N = 40). The occlusal and axial material thickness was 1.5 mm for all crowns.
Before the crowns were cemented, the intaglio surface of each crown was treated according to their manufacturer’s instructions. The ZIR crowns were air abraded with alumina powder with a mean particle size of 50 µm for 10 seconds at a pressure of 2 bars and a distance of 10 mm. The LDS crowns were etched with 5% IPS hydrofluoric acid gel (Ivoclar Vivadent) for 20 seconds. The HC crowns were air abraded with alumina powder with a particle size of 50 µm at a pressure of 1 bar until the entire bonding surface appeared matte. The ZLS crowns were treated using 5% hydrofluoric acid gel for 20 seconds, with VITA ceramics etch and silane bonding agent for 60 seconds (VITASIL, VITA Zahanfabrik). All crowns were thoroughly cleaned with water spray for 60 seconds, followed by ultrasonic cleaning in distilled water for another 60 seconds. Oil-free compressed air was applied to dry the intaglio surface. A ceramic primer was applied on the intaglio surface of the crowns for 60 seconds (Clearfil, Kuraray Noritake Dental Inc.). No surface treatments were used on the zirconia abutments. A self-adhesive resin cement (Panavia 21, Kuraray Noritake Dental Inc.) was applied on the intaglio surface of each crown. All crowns were cemented on zirconia abutments applying 5-pound weight pressure for 5 minutes to ensure complete seating, and the excess cement was carefully removed from the margins.

Simulating the clinical scenario of an abutment screw loosening, the screw access channel preparation was started with a water-cooled round diamond rotary instrument (grit size 150 µm) and a maximum rotational speed of 200,000 rounds per minute until complete perforation of the crown to abutment screw was achieved. A round-end tapered diamond rotary instrument (grit size 63 µm) was then used to complete the access channel preparation also under water-controlled conditions. The channel was 3 mm in diameter which was measured with a periodontal probe on each crown by the same operator (L.B.). After screw access channel
preparation, screw heads were located and the screw access holes were sealed with 2 Cotton pellets (Size #1, Richmond Dental Inc.) to cover the screw head. Then, a light-polymerized single component temporary composite resin (Telio CS Inlay, Ivoclar Vivadent) was used to plug the channels. Specimens were maintained in distilled water for 24 hours until the cyclic loading was performed. Cyclic loading was performed on 5 specimens of each material in a wet environment, using a frequency of 2 Hz and 5 million cycles with applied loads of 5 – 220 N to simulate 20 years of service.19 The specimens were secured with steel jigs in a vertical position. Polyoxymethylene balls (Delrin 6.28 mm, Dupont) were used during cyclic loading on the occlusal surfaces of crowns. The polyoxymethylene balls contacted both cusps during loading and therefore applied the loads on both opposing cusps. This set-up is based on a previous study and used to see if any damage to the surface that was introduced from making the occlusal access holes would continue to propagate and cause failure or weakening of the crown over time.20 The crown stability was checked at every 250,000 cycles to simulate a 1-year recall and detect any mobility with the crowns. After cyclic loading, all implants with their surviving crowns were secured on a steel jig before being loaded in a universal mechanical servohydraulic testing machine (Model M 812.21, MTS Inc.). A tapered cone-shaped (3.2 mm at the tip) applicator was placed vertically along the central groove of the maxillary premolar implant crown. The crosshead speed was set at 1 mm/min. Tests were done in standard laboratory conditions (22°C and 50% humidity). The maximum load-to-failure values were recorded as indicated by a sudden load drop and broken fragments were collected. The applied force was parallel to the longitudinal axis of the specimens. All specimens were loaded from 0 Newton (N) until fracture. The fracture load was recorded in Newtons. The fracture patterns were analyzed by visual inspection.
The load-to-failure data were first analyzed for equality of variance using Levene’s test, and data were further analyzed using a 2-way ANOVA with restricted maximum likelihood estimation, which preceded with Tukey-Kramer adjustments ($\alpha=.05$).

**RESULTS**

Two of the 20 specimens that were subjected to cyclic loading fractured catastrophically between 1 million and 2 million cycles. The zirconia abutment fractured under one LDS specimen (Fig. 3) and one ZLS crown fractured with no damage to the abutment (Fig. 4). All remaining specimens survived the 5 million loading cycle.

The mean load-to-failure values when only the static load was applied to the specimens were 2867.7 N (ZIR), 653.7 N (HC), 1189.2 N (LDS), and 882.1 159.0 N (ZLS). The mean load-to-failure values when the specimens were cyclically loaded before the static load was applied were 2568 N (ZIR), 670.3 N (HC), 867 N (LDS), and 825.8 N (ZLS). Figure 5 demonstrates the mean load-to-failure values, for cyclically loaded and unloaded specimens, including the 95% confidence limits. The data for the load-to-failure test series was found to be of an equal variation. ANOVA showed a statistically significant difference between the materials ($p < .05$). The ZIR crowns required significantly higher loads to fail than the other materials regardless of the presence of cyclic loading. No significant differences were found amongst ZLS, LDS, and HC. No effect of cyclic loading was found on the load-to-failure values. Three out of the five ZIR crowns, which didn’t undergo cyclic loading, had a unique fracture pattern after static loading: the crown and the abutment separated from the Ti-base. Table 2 gives a detailed overview of the fracture patterns of the different types of materials.
DISCUSSION

The results of this study suggest that the type of material used to fabricate cement-retained implant crowns has a significant effect on the load-to-failure values. ZIR had the highest mean load-to-failure value among the groups. Therefore, the first null hypothesis was rejected. The second null hypothesis was accepted as cyclic loading’s effect on the load-to-failure values was found not to be significant.

According to Hagberg et al, the average maximum posterior bite force is between 300 and 600 N. A similar study by Hussien et al. reported that monolithic zirconia with screw access channels had the highest load-to-failure when compared with veneered zirconia and lithium silicate implant crowns. Thus, these results are consistent with the current study in terms of the load-to-failure of crowns with access channels. In the current study, zirconia demonstrated high load-to-failure values and therefore, it may be recommended as a posterior restoration that would withstand high chewing forces for an implant-supported crown. Even though materials other than ZIR did not have significant difference amongst each other in the current study, ZLS crowns had higher load-to-failure values than the HC crowns. This result is in agreement with the results of another study; the resin infiltrated ceramic crowns (HC) had lower values than the ZLS, and the highest load-to-failure values were found in conventional LDS (e.max). Their study had a different test design with the thermal and mechanical loading, however, they converted the crowns into a (screw/bonded restoration) similar to the crowns in the current study. They proposed that the reduced fracture values could be due to the potential pre-damaging of the crown material while drilling the access hole. They suggested that designing an access hole in the restoration before milling might eliminate that concern. Another study found comparable load-to-failure values for resin hybrids, ZLS, and LDS using natural teeth in a
laboratory setting; the resulting fracture values in their study exceeded maximum chewing forces in a molar, which are expected to reach up to 900 N. Some authors reported that the biting forces of a male may be up to 1000 N during sleep with force durations many times longer than those observed in normal chewing. Therefore, the use of HC and ZLS in the posterior region should be further investigated before their routine use for patients with parafunctional habits, in a situation where screw access holes are drilled to tighten a loose screw. LDS and ZIR had load-to-failure values higher than 1000 N in the current study. Accordingly, they may have the potential to withstand the occlusal forces in the posterior region for implant crowns even after a screw access channel is drilled and sealed. Even though some crown materials had load-to-failure values lower than 1000 N in the current study, it should be noted that the cyclic loading’s effect was insignificant on all applied materials. This result was obtained even though the integrity of the crowns was jeopardized when manually drilling with diamond burs through occlusal surfaces. Furthermore, when interpreting the results, it should be taken into account that the standard thickness used in the current study for all crowns was 1.5 mm, which is the recommended minimum occlusal thickness for ZLS, LDS, and HC. However, the recommended minimum occlusal thickness for the zirconia used in the current study is 0.5 mm. Accordingly, even though the crown thicknesses were standardized across groups, the occlusal thickness in the ZIR group was three times higher than the recommended minimum.

It has been reported that a wet environment accelerates the chemical corrosion process in areas with cracks for ceramic crowns. However, the fact that the cyclic loading was applied in a wet environment in the current study didn’t result in fracture during cyclic loading except for one ZLS crown. In addition, one zirconia abutment under an LDS crown cracked right above the implant platform during cycling loading. Polyoxymethylene balls (Delrin; Dupont) were used
during cyclic loading to simulate an intraoral chewing pattern. The surfaces of the ball were in contact with both buccal and palatal cusps during cyclic loading which could have resulted in separating effect. The fracture pattern observed with one ZLS crown might have been due to this separating effect. An interesting finding is the fracture pattern of three of the ZIR crowns during static loading in which the failure occurred within the abutment body, specifically between the abutment walls and the Ti-base. In a study by Yilmaz et al, different zirconia abutments were evaluated for fracture strength and only the Legacy Contour abutments (same system used in the current study) had a load-to-failure higher than the other abutments. The authors suggested that it may be due to the notable thickness of the abutment zirconia walls. The same abutment system was used in the current study. The bond between the crown and the abutment was stronger than the bond between the zirconia abutment and the titanium base as the zirconia portions were separated from the Ti-bases.28 Aside from this unique fracture pattern, all remaining specimens in the current study showed similar mixed adhesive-cohesive cement failures.

In the present study, a temporary composite resin was used to seal the screw access channels to follow the institute’s clinical protocol for situations where screw loosening has been recorded and the crown is being monitored for future looseness until the 1-year hygiene follow-up appointment. This temporary resin is replaced with a permanent composite resin at the 1-year follow up in the clinical situation. The use of this temporary resin also helped for its easier removal with hand instruments without the need for high-speed rotary instruments, which may potentially damage the test crowns during their removal.

A limitation of the present study was that there was no control group without a screw access hole. However, it is well-known that ceramic crowns without drilled holes fabricated at thicknesses used in this study would be expected to fail under extremely high loads, much higher
than reported chewing loads in the literature. This is also supported by the already high failure loads almost all groups exhibited (even cyclically-loaded ones) in the current study, with a 3-mm hole at their center. Because chewing loads have been reported in many studies as also referenced in this study, comparisons of current study results with previously published data are possible. Because the primary focus of the present study was to analyze the influence of cyclic loading on implant crowns with drilled screw-access channels, the group without cyclic loading served as the control group. A limitation of the applied loading simulation was that the load-to-failure test didn’t represent the oral environment as the force was applied vertically non-stop until fracture. In addition, the fracture pattern was not evaluated using fractography. In vivo evaluation would support a firm determination of load-to-failure of different all-ceramic materials. The fact that Zr abutment surfaces were not treated before composite resin bonding may be considered as a limitation because lithium silicate and hybrid ceramic systems rely on composite resin bonding for improved strength per their manufacturer. Their failure load values might have been higher if the Zr abutment surfaces were airborne particle abraded and primer application was made. However, the impact of pretreating zirconia abutments on the strength of all-ceramic crowns hasn’t been clearly shown in clinical studies yet. Also, this study was limited to one implant system, one abutment, and one cement; having different systems and brands may result in varying outcomes.

CONCLUSION

Cyclic loading did not significantly influence the load-to-failure performance of any of the materials tested. The results suggest that zirconia crowns with drilled screw access channels cemented on zirconia abutment with a Ti-base had higher load-to-failure values compared to lithium disilicate, zirconia-reinforced lithium silicate, and hybrid ceramic crowns. Because high
load-to-failure was achieved even after the preparation of a screw access channel to simulate a clinical situation of a loose abutment screw, maintaining drilled-through zirconia implant crowns may be considered.

REFERENCES


TABLE/ FIGURE LEGENDS:

Table 1. Overview of tested materials. The material properties are reported according to the information provided by the manufacturer.

Table 2. Overview of fracture patterns with and without cyclic loading (ZIR: zirconia; LDS: lithium disilicate; ZLS: zirconia reinforced lithium-silicate; HC: hybrid ceramic)

Figure 1. Digital crown design on prefabricated zirconia abutment.

Figure 2. Crowns fabricated from different materials (from left to right: zirconia reinforced lithium-silicate, hybrid ceramic, lithium disilicate, zirconia)

Figure 3. Cracked zirconia abutment under a lithium disilicate (LDS) during cyclic loading

Figure 4. Zirconia reinforced lithium-silicate (ZLS) crown fractured during cyclic loading

Figure 5. Mean load-to-failure values and 95% confidence intervals for cyclically loaded and non-loaded crowns.
# TABLES AND FIGURES

## Table 1

<table>
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<tr>
<th>Material</th>
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<th>Manufacturer</th>
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<td>SUPRINITY</td>
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<td>Zirconium dioxide, ZrO₂</td>
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Table 2

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NA: Not applicable
Figure 1

Figure 2
Figure 3

Figure 4
Figure 5

![Graph showing failure load (N) for different materials and cyclic loading conditions.]