Fracture Load of Monolithic CAD/CAM Ceramic Crowns Placed on Different Implant Abutments

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Purpose: To evaluate the fracture load of monolithic, single-tooth implant-supported crowns cemented on solid or Ti-base (Variobase C) abutments. Materials and Methods: Besides abutment types (solid and Ti-base abutments), two ceramic systems (IPS e.max CAD and Zirconia inCoris ZI) and two occlusal thicknesses (0.5 and 1.5 mm) were also investigated in this study. In total, eight groups (n = 8) with 64 maxillary second premolar crowns were fabricated. All the crowns were cemented with resin cement, and the screw accesses in Ti-base groups were sealed with composite resin. After mechanical cycling, the specimens were submitted to fracture load test with the maximum force recorded in Newtons (N). Three-way analysis of variance (ANOVA) and Tukey post hoc test were used for statistical analyses (α = .05). Results: Both the abutment type (P = .0001) and the ceramic system (P = .0001) significantly affected the results. Screw-access channels reduced the fracture load of crowns by half compared to those cemented on solid abutments. The 1.5-mm and 0.5-mm zirconia crowns placed on solid abutments had similar highest fracture loads, while the e.max CAD groups positioned on Ti-base abutments showed significantly lower values compared with other groups. Conclusion: The screw access reduces the resistance of crowns supported by Ti-base abutments compared to crowns cemented on solid abutments. The inCoris ZI showed a higher fracture load than the IPS e.max CAD regardless of the abutment type and thickness. Int J Oral Maxillofac Implants 2022;37:1217–1222. doi: 10.11607/jomi.8855

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The manufacturing process for single-unit implant crowns became simpler and more efficient with the introduction and routine use of intraoral scanners in daily practice.1 The rationalization of processes and interactions with the dental prosthesis laboratory, or even with chairside use, allowed for the preparation of prosthesis abutments and provisional and definitive crowns with monolithic materials milled with CAD/CAM. Blocks of zirconia, lithium disilicate glass-ceramics, hybrid ceramics, and polymers have been recommended for these systems to manufacture implant restorations.1–3

Monolithic crowns have become an excellent treatment option due to significantly reducing failures, such as chipping, that occur with zirconia-based multilayer crowns.4–8 Both lithium disilicate glass-ceramics and zirconia stabilized by yttria present high modulus of elasticity, thus allowing for high masticatory loads to be applied to the material.9–11

Single-unit implant crowns can be placed on titanium or zirconia abutments, both of which demonstrate low rates of failure and biologic complications.12,13 Titanium is generally preferred due to its biocompatibility and mechanical properties. However, the wear between the interface of the titanium implant and the zirconia abutment led to the incorporation of new titanium interfaces attached to crowns of screwed and cemented single-unit implants.

This titanium interface abutment (Ti-base) features an integrated interface for an adhesive/titanium base and can be used for cemented, screwed, or screw-cemented crowns.12 The block perforations come in two sizes, small and large, for different implant diameters. The implant position is captured by a scanbody. The crown is designed, milled, and cemented extraorally, facilitating the removal of excess cement and thereby avoiding one of the causes of peri-implantitis.14,15 The assembly is screwed into the implant, torque is applied on the screw, and the hole is then sealed with composite resin.

Solid abutments are widely used in cases of cemented prostheses, mainly for manufacturing metal-ceramic
crowns. However, in a study by Stona et al., solid abutments were scanned and monolithic ceramic restorations were made, cemented, and tested as an alternative; the results were promising due to the high fracture load values.

Among the perforated CAD/CAM blocks on the market, there are no data about fracture strength in industrially drilled lithium disilicate and zirconia blocks. Thus, the effects of the presence of the screw access hole and the thickness of the ceramic on the fracture resistance of this material are still unknown. Therefore, this study had the objective of evaluating the fracture strength of monolithic disilicate and zirconia crowns milled, cemented on a solid abutment, and screwed/cemented on a Ti-base abutment with different occlusal surface thicknesses (0.5 and 1.5 mm). This study was developed under the hypotheses that (1) the presence of the screw hole reduces the fracture load of crowns made on a Ti-base abutment compared with those cemented on a solid abutment, (2) the restoring material influences the fracture load of crowns made on a Ti-base abutment compared with those cemented on a solid abutment, and (3) the thickness of the restoring material influences the fracture load of the restoration.

**MATERIALS AND METHODS**

**CAD/CAM Restorations**

The sample size was calculated using Sigmaplot version 12.0 software and based on a pilot study that considered the following parameters: type I error probability of .05, a minimum difference between means of 400 MPa, an expected standard deviation of residuals of 166, and a nominal test power of 0.9. The minimum sample size was eight (n = 8) specimens per group.

Implant analogs (Tissue Level RN, Straumann) were embedded in self-cured acrylic resin. A Ti-base abutment (Variobase C, Straumann) with a height of 5.0 mm and a solid abutment (RN Solid abutment, Straumann) with a height of 5.5 mm were placed with 35 Ncm of torque in accordance with the manufacturer's instructions (Fig 1). Eight groups (n = 8) were obtained according to the abutment, ceramic type, and thickness (Table 1).

![Fig 1](image1.png)  
**Fig 1** Samples made with Variobase C and solid abutments placed over analog of the Straumann Tissue Level RN implant.

![Fig 2](image2.png)  
**Fig 2** Drawing of the crown on the Variobase C abutment with 0.5-mm thickness.

![Fig 3](image3.png)  
**Fig 3** Crown occlusal thickness on solid abutment at 1.5 mm.

**Table 1 Experimental Groups**

<table>
<thead>
<tr>
<th>Group</th>
<th>Abutment</th>
<th>Ceramic</th>
<th>Thickness (mm)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>SZ15</td>
<td>Solid</td>
<td>inCoris ZI</td>
<td>1.5</td>
<td>8</td>
</tr>
<tr>
<td>SZ05</td>
<td>Solid</td>
<td>inCoris ZI</td>
<td>0.5</td>
<td>8</td>
</tr>
<tr>
<td>SE15</td>
<td>Solid</td>
<td>IPS e.max CAD</td>
<td>1.5</td>
<td>8</td>
</tr>
<tr>
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</tr>
<tr>
<td>TBZ15</td>
<td>Variobase C</td>
<td>inCoris ZI meso</td>
<td>1.5</td>
<td>8</td>
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<td>TBZ05</td>
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<td>0.5</td>
<td>8</td>
</tr>
<tr>
<td>TBE15</td>
<td>Variobase C</td>
<td>IPS e.max CAD A16</td>
<td>1.5</td>
<td>8</td>
</tr>
<tr>
<td>TBZ05</td>
<td>Variobase C</td>
<td>IPS e.max CAD A16</td>
<td>0.5</td>
<td>8</td>
</tr>
</tbody>
</table>

L = large block perforation. No small block perforations were applied in this study.

The Ti-base abutments were scanned with an intraoral scanner (Omnicam Connect, Dentsply Sirona) through the corresponding scanbody, and the solid abutments were scanned using the same scanner and a powder (CEREC Optispray, Dentsply Sirona) for better scanning performance. Crowns of lithium disilicate (IPS e.max CAD, Ivoclar Vivadent) and zirconia (inCoris ZI, Dentsply Sirona) were designed by InLab Software version 18 (Dentsply Sirona). Using a 3D printed model, a biogeneric copy of a maxillary right second premolar was fabricated on the Ti-base abutment. After milling, this crown was placed on the model, digitized, and used as a biogeneric reference for the solid abutment crown. Despite extrapolating the manufacturer's recommendation to the minimum thickness on the occlusal surface, the crown thickness of 0.5 and 1.5 mm were measured from the central sulcus to the top of the abutment (Figs 2 and 3). The parameters used for the
Crowns made on the solid abutment were 80 μm at the radial spacer, 80 μm at the occlusal spacer, and 60 degrees of margin angulation, with the geometry of the instrument not being taken into account. The crowns were then milled in the inLab MCX5 unit (Dentsply Sirona).

The zirconia crowns were sintered in the InFire HTC Speed (Dentsply Sirona) furnace according to manufacturer instructions, and lithium disilicate crowns were finalized in the Programat (Ivoclar) crystallization program. The samples were then polished (Universal HP rubber and Diapol HP, EVE Dental Products).

The internal surface of the crowns was prepared for cementation according to the manufacturer’s specifications as follows:

- inCoris ZI crowns were sandblasted with 50 μm aluminum oxide powder for 10 seconds, rinsed, and dried with water/air spray. A universal primer (Monobond N, Ivoclar Vivadent) was applied with a microbrush for 60 seconds, followed by air-drying.
- IPS e.max CAD crowns were etched with 5% hydrofluoric acid (Condac, FGM) for 20 seconds, rinsed, and dried. Monobond N was applied with a microbrush for 60 seconds, followed by air jet.

The crowns were cemented onto the abutments with a resin cement (Multilink N, Ivoclar Vivadent) under a cement load of 1 kg for 3 minutes. Excess cement was removed with a microbrush, followed by light curing with LED (Valo, Ultradent Products) for 20 seconds on each face with an intensity of 1,200 mW/cm². The screw access channels of the crowns cemented on Ti-base abutments were filled with composite resin (Empress Direct, Ivoclar Vivadent) and light cured for 20 seconds. The specimens were stored in distilled water at 37°C for 24 hours prior to the mechanical cycling process.

Cyclic Mechanical Loading
The samples were submitted to cyclic loading. The load profile was always in contact with the occlusal surface of the crowns at 200 N using 500,000 cycles at 1 Hz in distilled water at 37°C.17,18 At the end of the cyclic loading, the samples were visually evaluated to determine if there was any failure, such as crown debonding, cracks, splinters, or ceramic fractures.

Fracture Load Testing
Fracture load testing was performed in a universal testing machine (DL2000, EMIC) using a cell load of 10 kN and a crosshead speed of 1 mm/minute. The compression load was applied parallel to the long axis of the crown with a metal sphere 6 mm in diameter until it fractured, and the maximum load was recorded in Newtons (N). After fracture load testing, the samples were visually assessed to observe the failures.

Statistical Analysis
Fracture load values were submitted to Shapiro-Wilk test. As there was normality, the results were analyzed by three-way analysis of variance (ANOVA; variation factors: ceramic type, thickness, and abutment type), followed by Tukey test (α = .05). The software used was Statistix for Windows 8.0 (Analytical Software).

RESULTS
In the present study, none of the crowns revealed defects in the form of cracks, chipping, fractures, or crown debonding after cyclic mechanical loading.

Table 2 shows the mean values of fracture load of the different groups.

According to three-way ANOVA, the ceramic (P = .0001), the abutment (P = .0001), and the thickness (P = .0304) presented significant influence on the study. The interaction between the ceramic and abutment was significant (P = .0001). The interaction between the ceramic, abutment, and thickness was significant (P = .04).

Considering all abutments and ceramics, the restorations with a thickness of 1.5 mm (2,584 N) did not show a mean fracture load statistically superior to the 0.5 mm restorations (2,345 N; P = .40).
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The fracture load values of the restorations in IPS e.max CAD (1,978 N) and inCoris ZI (5,089 N) on the solid abutment were statistically higher than the restorations in IPS e.max CAD (944 N) and inCoris ZI (1,847 N) cemented on Variobase C. The inCoris ZI crowns presented a statistically superior fracture load to those obtained with the restorations in IPS e.max CAD, regardless of the type of abutment (Table 3).

The failure predominance after the fracture test corresponded to a fracture line that divided the restoration into two parts, buccal and palatal. In most samples of the TBE05 and TBE15 groups, the buccal face of the crown was retained on the abutment (Fig 4). In the solid abutment groups, the samples were divided into two, three, or more parts (Fig 5).

DISCUSSION

The perforated crowns cemented on the Variobase C abutment had a lower fracture load than the crowns cemented on the solid abutment ($P = .0001$). Thus, the first hypothesis of the study was accepted. This finding corroborates a study by Rosentritt et al. However, these authors made the screw access by hand with a diamond bur at high speed. It is possible to speculate that this procedure could cause predamage in the ceramic and thus decrease the resistance of the material. In the present study, ceramic blocks with perforations made by the manufacturer were used. In this way, failure and cracking due to the use of a diamond bur would be minimized or avoided.

Regardless of the screw access method, a possible explanation for the lower fracture resistance is that the site of the perforation causes loss of continuity in the restorative material, as well as being the location where the stresses are concentrated at the time of the fracture test. In this way, the fracture gap propagates more easily under a lower load. Priest stated that the potential weakness of ceramic discontinuity in screw access channels can be reduced by the use of more fracture-resistant ceramic materials such as zirconia and lithium disilicate. However, crowns made from the same ceramic materials cemented on the solid abutment were significantly more resistant to fracture in the present study.

The results obtained do not agree with a study by Hussien et al., in which lithium disilicate, zirconia, and multilayer crowns (zirconia with application of IPS e.max Ceram) were 1.5-mm thick, lacked screw access, and showed no significant difference in fracture strength. A possible explanation for the contradictory results may be related to geometric differences in the titanium abutments used in the studies.

The crowns made with zirconia showed significantly higher fracture loads than the lithium disilicate crowns, validating the second hypothesis. According to the manufacturers, the inCoris ZI ceramic presents a flexural strength ($> 900$ MPa) and modulus of elasticity ($210$ GPa) superior to that of IPS e.max CAD ceramics ($360$ MPa and $95$ GPa, respectively), which justifies the results found. The highest mean value of fracture load was obtained for inCoris ZI crowns cemented on the solid abutment (5,089 N), and the lowest average was obtained for the IPS e.max CAD crowns cemented on the Variobase C abutment.
abutment (944 N). Waltimo and Könönen,21 who evaluated patients with temporomandibular disorders, recorded a mean occlusal force of 909 N (± 177) for men and 777 N (± 168) for women. This information would place the cemented IPS e.max CAD crowns on the Variobase C abutment clinically at risk. However, Ferrario et al22 showed that patients without temporomandibular disorders have a mean occlusal force of 291 N in the premolar region. Thus, the professional must be aware of the factors of tooth location in the dental arch and the presence of parafunctional habits to select the correct type of abutment, material, and thickness of ceramic.

The restorative material thicknesses of 0.5 and 1.5 mm in the occlusal region was another study factor. Considering only the thickness, the results showed that the crowns with 1.5 mm of occlusal thickness obtained a mean fracture load (2,584 N) similar to that of 0.5 mm (2,345 N; P = .40). In this way, the third hypothesis was not accepted. It is estimated that this reduction would not be clinically relevant, especially for the InCoris Z1 crown groups and the group with an IPS e.max crown cemented on a solid abutment, since the values are well above the maximum masticatory load of 847 N for men and 597 N for women in the molar region reported by Waltimo and Könönen.21 However, according to the manufacturer, the e.max CAD ceramic system, when used in crowns on Ti-base abutments, must have a surrounding thickness of at least 1.5 mm and should not exceed 6.0 mm from the axial height of the contour to the screw channel. The authors of the present study used a thickness of 0.5 mm, considering the clinical situation where there is a reduction of the interocclusal space, which would allow the option of using an abutment of greater height to improve the retention of the crown and make the prosthetic with a thinner ceramic. The results observed in Table 2 do not corroborate the e.max CAD manufacturer’s recommendations regarding the minimum thickness of 1.5 mm (963 N) on Ti-base abutments, since there was no statistical difference in relation to the thickness of 0.5 mm (924 N). However, the values are above the previously reported maximum occlusal load. In turn, in a study by Sorrentino et al23 which evaluated the fracture strengths of different thicknesses of zirconia, it was concluded that a thickness of 0.5 mm supported the forces well when cemented on the tooth. Thus, because the interaction between the ceramics, abutments, and thicknesses was significant (P = .04), it can be inferred that the type of abutment used will favor the mechanical behavior of the ceramic systems used in the present study, even at reduced thicknesses of 0.5 mm.

In the present study, the crowns were subjected to 500,000 cycles with a load of 200 N. Mechanical cycling is an in vitro aging methodology that aims to subject the specimens to a cyclic load, trying to reproduce the masticatory loads that are applied to the restorations. In this way, the normal functions of approximately 2 years were simulated, since 250,000 cycles are equivalent to an average of 1 year.24 For all experimental groups, the mechanical cycling did not cause cementation failure, fractures, chipping, or cracks in the surface, evidencing that loads of up to 200 N would not be deleterious to the restorations.

The crowns were cemented with the dual polymerization resin cement using the adhesive technique. The IPS e.max CAD is acid sensitive, and InCoris Z1 is acid resistant.11 However, Weyhrauch et al25 evaluated the differences in fracture strength between cemented crowns made of seven different monolithic ceramic materials and five different cementing agents, and the results showed that there was no significant difference for any cements used and that they had no influence on fracture resistance. Also, according to Lopes et al,26 the resin cement presented adequate resistance in the attempt to remove the crown compared with the temporary cement on the Ti-base abutment, independent of the crown material (acrylic resin, cobalt-chromium alloy, zirconia, or titanium).

One of the limitations of this in vitro study was the anatomical difference in the abutments (height, base of foundation, angulation of the walls) because it is believed that the fracture strength of ceramic crowns can be affected by the abutment composition and height.27 However, it was evident in the present study that the type of abutment can influence the mechanical strength of prosthetic crowns.

The perforated blocks of zirconia and lithium disilicate improved the esthetic potential of screwed crowns compared with traditional metal-ceramic implant prostheses, whose esthetics were impaired by the apparent metal in the orifice and could be comparable to cemented crowns. However, the results of the present study corroborate the findings of Priest,12 who indicated that the ceramic discontinuity of the screw access could make the associated crowns more prone to fracturing. Some of this evidence might not be conclusive and convincing enough to affect the choice between screwed and cemented prostheses. However, the present study showed that a lower force was required to fracture ceramic crowns placed on Variobase C abutments compared with solid abutments.

In this sense, if the choice of the dentist is only supported by the mechanical resistance provided by the abutment and crown set, the use of solid abutments is reported in the literature as an excellent option.16 However, in the systematic review conducted by Saier et al15 regarding complications and survival rates of cement- versus screw-retained crowns, it was reported that both types of prostheses influence clinical outcomes in different ways. Cement-retained prostheses had more biologic complications (implant loss, bone loss > 2 mm), while...
screw-retained prostheses presented more mechanical problems.

Due to the new findings reported in this study, clinical studies are needed to define the potential, limits, and long-term maintenance of the combination of monolithic materials on both the solid abutment and the Ti-base abutment system.

CONCLUSIONS

Based on the proposed objectives and methodology used in this study, it can be concluded that:

1. The screw access channel of the Variobase C abutment reduced the fracture load of the IPS e.max CAD and inCoris ZI crowns by half compared to solid abutment crowns.
2. The inCoris ZI showed a higher fracture load than the IPS e.max CAD, independent of the abutment and thickness.
3. The thickness of the restorations (0.5 and 1.5 mm) had no influence on fracture load.

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