Fracture Resistance of Custom Lithium Disilicate Implant Restorations with Two Fabrication Techniques and Two Designs

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Purpose: To compare the fracture resistance of a press-on ceramic custom implant restoration with pressed and cemented restorations. Materials and Methods: Thirty-two (32) lithium disilicate (IPS e.max Press) custom hybrid abutment restorations were fabricated. The restorations were divided into two groups (n = 16) according to the construction technique: the commercial control group (C) and the press-on group (P). For the control group, lithium disilicate restorations were pressed and cemented on titanium bases. For the press-on group, lithium disilicate pressable ceramic (IPS e.max Press) was pressed on the titanium bases with injection molding. Each group was further divided according to the restoration design, either screw- or cement-retained, into two subgroups of eight specimens each. Specimens of C group were divided into screw-retained (cemented hybrid abutment crown, CHAC) or cement-retained (cemented hybrid abutment, CHA). Specimens of the P group were also divided into screw-retained (pressed hybrid abutment crown, PHAC) and cement-retained (pressed hybrid abutment, PHA). The specimens were subjected to static loading until failure with a universal testing machine. Two-way analysis of variance (ANOVA) was used to assess the effect of different techniques and designs on the fracture resistance of the samples (P < .05), followed by one-way ANOVA and Tukey honest significant difference (HSD) test (α = .05). Results: C group showed higher mean fracture resistance (812.44 ± 129.14 N) than P group (596.71 ± 108.83 N), and the difference was statistically significant (P < .05). Regarding restoration design, HA groups showed higher mean fracture resistance (742.62 ± 153.82 N) than HAC (666.53 ± 163.07 N) groups with no statistically significant difference. CHA showed the highest mean fracture resistance (817.65 ± 161.76 N), while PHAC showed the lowest mean fracture resistance values (525.83 ± 47.29 N). Conclusion: The commercial cemented lithium disilicate restorations showed higher fracture resistance than the press-on restorations, although both showed a maximum load capacity that was greater than physiologic incisal force in the anterior region, and both hybrid abutments and hybrid abutment crowns were equally efficient in withstanding occlusal loading forces. Int J Oral Maxillofac Implants 2022;37:677–684. doi: 10.11607/jomi.9657

Keywords: abutment design, dental implants, fracture resistance, IPS e.max Press, lithium disilicate, pressable ceramics
of fabrication, reduced cost, reduced chairside time, and higher passivity of fit as distinct advantages.\textsuperscript{8,14} Regarding abutment materials, titanium (Ti) is considered a gold standard despite being considered unesthetic in certain clinical situations, creating a need for an esthetic alternative.\textsuperscript{5,15} Zirconia ceramic is one such esthetic alternative that has attracted significant interest, leading to its use as an implant abutment due to its well-documented high fracture resistance, good esthetics, and superior biocompatibility. However, low translucency, porosity, and whitish color can compromise optimal esthetic results.\textsuperscript{5,13} On the other hand, as glass-ceramic technology continues to improve, recent literature has shown that glass-ceramics that contain lithium disilicate crystals may also serve as an esthetic option for implant abutments.\textsuperscript{14} Pressable lithium disilicate restorations (IPS e.max Press, Ivoclar Vivadent) demonstrate a flexural strength of 400 MPa.\textsuperscript{16} Meanwhile milled lithium disilicate restorations (IPS e.max CAD, Ivoclar Vivadent) are fabricated using CAD/CAM technology and demonstrate a flexural strength of 360 MPa,\textsuperscript{16} not to mention the added reinforcement effect by resin cementation. The variation in strength is due to the longer micro-crystal structure.\textsuperscript{17} Along with strength and esthetics, there are some other factors to consider as well: e.max Press has superior surface quality and smoothness, cleaner and more precise margin integrity, less chipping, smoother margin lines, less wear on the opposing teeth, and a higher level of detail compared to e.max CAD.\textsuperscript{17} Recently, the new IPS e.max hybrid abutment or hybrid abutment crown fabricated by either CAD/CAM or pressing technology was launched.\textsuperscript{14,18} Restorations may be used as an abutment bonded to a Ti insert supporting a crown or as a combination abutment and crown, where the abutment and crown are fabricated in one piece that will be bonded to a Ti insert and screwed to the implant. The screw access hole is subsequently closed with composite resin.\textsuperscript{15} An early attempt to fabricate a pressable metal-ceramic custom implant abutment was reported in 2009 by Kim et al,\textsuperscript{7} who fabricated a cast abutment from a ceramic alloy after waxing a gold implant-level abutment and replacing it with lithium disilicate by pressing. Fracture resistance was compared to that of a zirconia abutment, and the results revealed that the mean fracture load was significantly higher than the zirconia group. Another attempt followed in 2013 by Protopapadaki et al,\textsuperscript{1} and the press-on customized abutment combining gold alloy and leucite pressable glass-ceramic also had significantly higher fracture load than zirconia abutments. Type IV gold alloy may have been used in both studies instead of titanium as the abutment material—despite being cost prohibitive—because of its coefficient of thermal expansion (CTE), which is compatible with lithium disilicate. The general consensus is that the alloy should have a higher thermal expansion coefficient than the porcelain or a positive expansion coefficient mismatch in order to produce compressive stresses in the porcelain on cooling.\textsuperscript{15} Usually, a variation ranging from 0.5 to $1.0 \times 10^{-6} \degree \text{C}^{-1}$ between the CTEs of the alloy and ceramic is considered adequate.\textsuperscript{20} In a 2009 study, Lopes et al\textsuperscript{20} stated that there was no correlation between metal-ceramic bond strength and CTE differences in metal-ceramic combinations in their study. In accordance with their results, Walton and O’Brien,\textsuperscript{19} Steiner et al,\textsuperscript{21} and Sipahi and Ozcan\textsuperscript{22} doubted the concept that the alloy should have a higher thermal expansion coefficient than the porcelain as they tested the metal-ceramic bond strength in samples with a negative CTE and found no significant differences from other groups with positive CTE.

The purpose of this study was to fabricate press-on screw-retained and cement-retained e.max custom implant restorations with a press-on Ti base technique and compare the fracture resistance with commercial hybrid abutment and hybrid abutment crown restorations fabricated by pressing and cementation to Ti bases. The null hypothesis was that there was no difference in fracture resistance between the press-on and cemented e.max restorations.

**MATERIALS AND METHODS**

Thirty-two 15.5-mm-long implant replicas (Astra Tech) of 4.5/-5-mm-diameter implants were aligned by a surveyor (AP100 parallelemeter, Amann Girrbach) and inserted in epoxy resin blocks (Ivolen custom tray resin material, Ivoclar Vivadent). Then, they were randomly distributed into four groups of eight specimens each and restored, simulating the restoration of a maxillary central incisor. The groups were divided according to fabrication technique and restoration design as follows: group I (CHA): a hybrid abutment crown pressed as one piece and bonded to a Ti base; group II (CHA): a crown cemented on a hybrid abutment bonded to a Ti base; group III (PHAC): a hybrid abutment crown pressed as one piece over a Ti base, and group IV (PHA): a crown cemented on a hybrid abutment pressed on a Ti base (Figs 1 and 2). An overview of the study design is demonstrated in Fig 3.

**Fabrication of Cemented e.max Press-On Ti Base (C) Restorations**

A Ti base (ATOS 4.5/5, Sirona Dental Systems) was screwed to an unmounted implant replica and painted with separating medium. A wax-up of a maxillary central incisor was built with the following dimensions: 11.2-mm length, 7.1-mm faciolingual width, and
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8.6-mm mesiodistal width. Two putty indices (Speedex Putty and universal activator, Condensation Silicone, Coltene Whaledent) were made on the wax pattern—one sectioned mesiodistally and one sectioned in a buccolingual direction—and used to make eight identical HAC wax patterns. An extra HAC wax pattern was made and modified to an abutment by shortening it 2 mm incisally and carving an anatomical 1-mm-deep chamfer finish line all around, following the guidelines for preparation of an IPS e.max crown. The finish line was 2 mm away from the Ti base finish line labially and palatally and 3 mm away proximally. Another two putty indices were made for the abutment to be used in the fabrication of another seven HAs.

Fig 1 Schematic drawing showing HAC restoration composition and dimensions. A: proximal view, B: labial view. 1: Ti Base, 2: e.max abutment crown.

Fig 2 Schematic drawing showing HA restorations composition and dimensions. A: proximal view, B: labial view. 1: Ti base, 2: e.max abutment, 3: e.max crown (white).

Fig 3 Flowchart showing an overview of the study design.

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A small drop of wax was used as a mark opposite to the antirotational lock on the Ti base for accurate positioning after pressing. A 6-cm dental floss was knotted each 1 cm along its length for each abutment and passed through the screw channels, and all were tied at the top to allow them to be pulled together while pouring the investment to ensure the investment was completely carried into the screw channels without air bubble formation. After spruing and investing, pressing was completed, and the HACs and HAs were passively seated on their Ti bases.

The CHAs were then used for constructing the wax patterns of their corresponding crowns. The abutments were painted with separating medium before wax patterns for the crowns were built, guided by the putty indices. The abutments and their corresponding wax crowns were numbered and marked during buildup and pressing to avoid confusion and to make sure each crown was fitted on its corresponding abutment after pressing. All Ti bases were attached to the analogs with Ti screws. Screws were tightened to 30 Ncm, then retorqued after 10 minutes. The bonding areas were air abraded with 100-µm Al₂O₃ for 5 seconds at 2 bars until a 6-cm dental floss was knotted each 1 cm along its length for each abutment and passed through the screw channels, and all were tied at the top to allow them to be pulled together while pouring the investment to ensure the investment was completely carried into the screw channels without air bubble formation. After spruing and investing, pressing was completed, and the HACs and HAs were passively seated on their Ti bases.

The HAC and HA samples were cemented following the same protocol. The bonding surfaces of the pressed samples were etched with 9% hydrofluoric (HF) acid etch (Ultradent porcelain etch, 9% buffered HF acid, Ultradent) for 20 seconds, thoroughly rinsed with air-water spray, and completely dried. The clean bonding surfaces were then treated with silane coupling agent (Ultradent Silane, Ultradent) and left to react for 60 seconds. For cementation, automix dual-polymerized self-etch, self-adhesive resin cement (TotalCem, Itena) was used. The mark opposite to the antirotational feature was used as a guide, and heavy finger pressure was applied. The margin was polymerized for 5 seconds for easy removal of excess cement; then the sample was put in a loading device under a 1-kg load, and the margin was polymerized from the four opposing directions for 20 seconds. The screw channels were blocked with composite restorative material (Nexcomp Nano Hybrid Composite, Meta Biomed) in small increments and polymerized for 40 seconds each. The crowns of CHA restorations were cemented following the same protocol and materials.

**Fabrication of e.max Press-On Ti Base (P) Restorations**

The Ti bases were screwed to the analogs before sandblasting the Ti base. Eight wax patterns of PHAC and PHA were built directly on the bonding surface with the same dimensions as the C group and guided by the putty indices. The wax patterns attached to their Ti bases were invested, and lithium disilicate ingots were pressed to the Ti bases (Fig 4). The crowns of the PHA group were constructed following the same steps as for the CHA group. The screw channels of PHAC and PHA were treated with HF and silane coupling agent and blocked with composite resin; the crowns of the PHA group were cemented on their corresponding abutments; and all samples were stored in distilled water at room temperature for 24 hours before testing.

All specimens were mounted in a custom-made steel holder at an angle of 30 degrees in relation to the direction of load application. The holder was fixed to the lower compartment of a universal testing machine with a load cell of 5 kilonewtons (kN), and data were recorded. The custom load applicator was a steel rod with a flat end and a 10 mm × 10 mm rectangular cross section placed at the incisal edge of each tooth and attached to the upper movable compartment of the machine. The maximum load to produce fracture for each specimen was automatically recorded in newtons (N). Samples were subjected to a slowly increasing vertical load (0.5 mm/min) until the fracture occurred. The load at failure was manifested by an audible crack and confirmed by a sharp drop in the load deflection curve recorded using the computer software. The obtained data were collected, tabulated, and presented as mean and standard deviation values, then statistically analyzed using SPSS for Windows (Statistical Package for Scientific Studies 19.0, IBM). Two-way analysis of variance (ANOVA) was used to assess the effect of different techniques and designs on the fracture resistance of the samples. One-way ANOVA was then performed to determine the significance of the difference between the means, and post hoc tests with Tukey honestly significant difference (HSD) method were performed for multiple comparisons and interactions between the variables.
RESULTS

The fracture resistance values of all groups are shown in Fig 5. It was observed that CHA showed the highest mean fracture resistance (817.65 ± 161.76 N), while PHAC showed the lowest mean fracture resistance values (525.83 ± 47.29 N).

Two-way ANOVA showed that the C group had higher mean fracture resistance (812.443 ± 129.14 N) than the P group (596.71 ± 108.83 N) regardless of the restoration design, and the difference was statistically significant (P < .001) However, the HA group had higher mean fracture resistance (742.621 ± 153.82 N) than the HAC group (666.53 ± 163.07 N), but the mean difference was not statistically significant (P = .063; Table 1).

One-way ANOVA test showed high significance in the comparison of the mean fracture loads between all four groups tested (P < .001; Table 2). All the groups were then intercorrelated against each other, with multiple interactions between the variables to identify if there was any significance amongst their mean values. This was performed with the Tukey HSD post hoc test, the results of which are presented in Table 3, with the shaded areas denoting significance, and the unshaded areas indicating no statistical significance.

The failure modes of the specimens were examined after the load at fracture test. The failure modes of all specimens are shown in Fig 6. Mode of failure analysis showed three patterns: catastrophic fracture in the ceramic leaving only Ti base, bending and fracture of the screw with intact ceramic restoration, and chipping of a part of the ceramic restoration. The fractured samples were examined using a handheld digital microscope with a built-in camera fitted on a precision microscopic stand (Dino-Lite Pro, AnMo) and connected to a personal computer using a magnification of ×40 to study the fracture pattern and determine samples and areas of interest to photograph. CHAC and CHA samples fractured by vertical split analysis showed that the cement layer was attached to the ceramic surface, indicating adhesive failure between the resin cement and surface of the Ti base (Fig 7). The PHAC and PHA groups showed a thin discolored layer on the bonding surface of the ceramic and the Ti base (Fig 8).

Table 1 Two-way ANOVA for the Effect of Pressing Technique and Restoration Design on the Fracture Resistance of Custom Hybrid Abutment Restorations

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig</th>
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<td>151043.029</td>
<td>12.187</td>
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<tr>
<td>Total</td>
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<td></td>
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<tr>
<td>Corrected Total</td>
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<td>31</td>
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aR squared = .566 (adjusted R squared = .520).
bSignificant at P < .05.

Table 2 One-way ANOVA Test

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<td>28</td>
<td>12394.048</td>
<td></td>
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<tr>
<td>Total</td>
<td>800162.436</td>
<td>31</td>
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Table 3 Results of the Tukey HSD Post Hoc Test

<table>
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<th>(A)</th>
<th>(B)</th>
<th>Mean difference (A-B)</th>
<th>Sig</th>
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aSignificant at P < .05.
The null hypothesis was partially rejected, as no differences were found between the different restoration designs (HAC and HA). However, the C group showed higher resistance to fracture than the P group. Although significant differences in the maximum load capacity existed among some groups, all of them exceeded the physiologic incisal force in the anterior region, which is known to be in the range of 150 to 235 N with a mean of 206 N.\\n
The results of this study showed that C restorations had a significantly higher mean fracture resistance than the P restorations regardless of the design. This may be due to the negative mismatch in CTE between the alloy (Ti-6Al-4V, CTE = 8.4–8.8 × 10^{-6} °C^{-1}) and the ceramic (Li_2S, CTE = 10.2 × 10^{-6} °C^{-1}). However, this concept is doubted by some authors, who stated no correlation between metal-ceramic bond strength and CTE differences in metal-ceramic combinations in their studies. No comparison data is available in the literature regarding the performance of press-on hybrid abutment restorations. The closest basis for comparison is represented by the two studies conducted by Kim et al and Protopapadaki et al in 2009 and 2013, respectively, as first attempts to fabricate pressable abutments for anterior implants. In their studies, the press-on abutments showed superior performance. Different methodologies and different materials with different CTE may have caused the variability between the results.

In this study, C groups depended on resin cement to increase the interfacial surface toughness of the ceramic, and the cemented samples may have fractured at higher values as the cement absorbed and dissipated the stresses generated in the samples during load application or strengthened the connection and allowed them to withstand higher forces. Moreover, there is evidence to suggest that the adhesive resin cements may contribute to the clinical longevity of ceramic restorations by decreasing the probability of crack initiation from the internal surface. On the other hand, the P samples are believed to be retained to their corresponding Ti bases mainly through mechanical retention. As titanium oxidizes rapidly, only low-fusing dental porcelains with firing temperature less than 800°C are available for veneering. A band-like oxidation layer on the titanium surfaces was usually noted with temperatures over 900°C and dramatically decreased the ceramic–titanium bond strength. The high temperature used for pressing lithium disilicate might be responsible for oxide formation in this study. It was believed that the oxides also might have retained the lithium disilicate and Ti base chemically.
The results of this study also showed that regardless of the technique used, the fracture resistance of HA was insignificantly higher than HAC ($P = .063$). Many authors$^8$–$^{12}$ believe that the screw access hole in HAC restorations can weaken the restoration, resulting in ceramic fracture as the screw access hole of the HAC restoration disrupts the structural continuity of the ceramic and replaces it with a weaker composite resin material. Silva et al$^31$ explained frequent screw loosening as a common incidence in screw-retained restorations as a result of forces in the screw-retained restorations being transmitted to the screw and the implant, whereas the cement-retained restoration has an intermediate buffer zone of cement acting as a cushion to reduce the forces being transmitted to the screw.$^{15}$ A lot of studies are in agreement with the results of this study that screw- and cement-retained implant restorations are equally efficient in restoring implants.$^8,^{15,18,32,33}$ On the other hand, Roberts et al$^{14}$ studied the fracture resistance of screw- and cement-retained restorations and reported that separating the abutment and crown inherently produces a weaker overall prosthetic restoration than fabricating a full-contour abutment crown design. Meanwhile, other studies showed that in metal-ceramic restorations, porcelain fracture resistance was lower in screw-retained than in cement-retained restorations.$^{34}$

The results of the one-way ANOVA and Tukey post hoc test in this study showed that CHAC had higher significant mean fracture resistance than PHAC, which may be due to the strengthening effect of the cement in CHAC samples. The mode of failure of CHAC samples showed 100% catastrophic vertical splitting of the ceramic restoration with adhesive failure between the cement and the Ti base. This may be due to the existence of the occlusal access hole, which disturbs the structural integrity of the restoration and increases the tension, with stress peaks laterally in the occlusal area. Additionally, the increased ceramic thickness might have played a contributing role in current fracture modes.$^6,35$

All samples showed adhesive failure with the Ti base, confirming the strong bond of HF and silane surface treatment with ceramics. However, the PHAC samples showed three different failure patterns: (1) vertical split by adhesive failure of the cement with the Ti base in 50% of the cases; (2) screw fracture in 37% of the cases, and (3) 13% chipping of the ceramic restoration (one sample). On the other hand, in the CHA group 63% and 37% of the samples failed with a fractured screw and a vertical split, respectively. Samples failing by screw fracture may be due to the strengthening effect of bonding the Ti base, abutment, and crown with resin cement in this group, with the cement acting as a stress breaker and making the screw the weakest link in the whole structure, causing its deformation and fracture. Meanwhile, 87% of the PHA samples failed with vertical split of the ceramic restoration, and one sample (13%) failed with screw fracture.

The microscopic analysis of the fractured samples confirmed the static load test results. In the cemented samples, the resin cement layer was attached to the lithium disilicate, indicating adhesive failure with the Ti base. In the pressed samples, a black, thin, discolored layer was attached to the lithium disilicate and Ti base bonding surfaces that is believed to be an oxide layer formed on the Ti base bonding surface during ceramics pressing. To adequately control this study, vertical loading was ensured by the vertical alignment of the implant replicas with the aid of surveyor; the wax patterns of all groups were fabricated with standardized putty indices; all groups were torqued to 30 Ncm, left for 10 minutes, and retorqued to 30 Ncm to decrease screw loosening during the static load test$^{15}$; and cementation under load was done to ensure complete seating. Meanwhile, static load application using a universal testing machine was used in the present study. This represents a limitation of the study, and more clinically relevant data could be obtained using a different testing method; a chewing simulation might be necessary to verify the present findings.

CONCLUSIONS

1. The cemented lithium disilicate pressed hybrid restorations showed higher fracture resistance than the press-on restorations, although both showed fracture resistance higher than physiologic incisal force in the anterior region, while different restoration designs had no effect on fracture resistance.

2. In screw-retained restorations, cemented hybrid abutment crowns showed higher fracture resistance than pressed hybrid abutment crowns, while in cement-retained restorations, the construction technique did not affect the fracture resistance of the implant-supported restorations investigated.

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REFERENCES


