Occlusal Thickness and Cement-Type Effects on Fracture Resistance of Implant-Supported Posterior Monolithic Zirconia Crowns

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Purpose: To evaluate the factors that could influence the fracture resistance of implant-supported posterior monolithic zirconia crowns. Materials and Methods: Sixty zirconia molar crowns with three different occlusal thicknesses of 0.5, 1.0, and 1.5 mm (20 samples per group) were prepared for implant abutments using a CAD/CAM system. In each group, 10 crowns were luted on the abutment with resin cement (Panavia F), and the other 10 crowns were luted with resin-modified glass-ionomer cement (Ketac Cem Plus). Dynamic loading (1.2 × 10^6 cycles; 70 N) and thermal cycling were applied to the samples using a chewing simulator before evaluating their fracture resistance with a universal testing machine and examining their fracture type using a stereomicroscope. One-way analysis of variance (ANOVA), the Duncan test, and two-way ANOVA were used for data evaluation (α = .05). Results: The occlusal thickness (P < .001) and cement type (P < .01) affected the fracture load of the monolithic zirconia crowns. The highest fracture resistance was found in 1.5-mm-thick crowns luted with resin cement (4,212 ± 501 N), and the lowest fracture resistance was found in 0.5-mm and 1-mm-thick crowns luted with resin-modified glass-ionomer cement (1,198 ± 116 N and 1,197 ± 66 N). A significant difference was not found in the mean maximum fracture load between the 1.5-mm-thick crowns cemented with resin cement and glass-ionomer resin cement. Conclusion: Both the occlusal thickness and cement type remarkably affected the fracture resistance of the crowns, but occlusal thickness was more significant. Implant-supported posterior zirconia crowns can withstand physiologic occlusal forces even with a thickness as low as 0.5 mm. Resin luting cement is recommended for implant-supported posterior zirconia crowns with reduced occlusal thickness. Int J Oral Maxillofac Implants 2021;36:485–491. doi: 10.11607/jomi.8503

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Monolithic zirconia restorations are alternatives to veneering layer zirconia restorations in terms of fracture resistance, especially for tooth-supported posterior crowns, prostheses, and implant-supported fixed partial dentures.1–6 Occlusal surface thickness is one of the major factors influencing the fracture resistance of full ceramic crowns.1,3–5,7 However, when the interocclusal distance is not adequate or a clinically short crown exists, a reduction in the occlusal thickness of crown restoration is needed.3,6–9 In conventional all-ceramic crown restorations, an occlusal thickness of 1.5 mm and 2.0 mm is usually suggested for restoration.5 Since zirconia has high flexural strength, monolithic zirconia crowns may exhibit adequate fracture resistance even at a reduced thickness.3,5 However, this is a controversial issue. While there are studies that suggest that monolithic zirconia crowns in the molar region with decreased occlusal thickness are more prone to failure than crowns with a 1.5-mm thickness, there are other studies that do not show the same result.3,5,9

Implant-supported monolithic zirconia crowns and prostheses can be preferred due to the esthetic expectations of patients and doctors.2,3,10–13 However, osseo-integrated implants directly connected with bone have no periodontal ligament and periodontal receptors. This leads to increased load on the implant restoration and fracture of the ceramic, which is seen more frequently in implant-supported restorations than natural teeth.3,14–17 Thus, occlusal forces become more important in implant-supported restorations than natural teeth, especially where the interarch space is reduced. Physiologic occlusal forces at the posterior region have different ranges from 250 to 900 N.3,9,18–20

The fracture resistance of restorations is also affected by cement type.14,15,21–24 It is known that resin cement increases the strength of the restoration, especially in all-ceramic and implant-supported fixed prostheses.
partial dentures. In the studies, resin cement or resin-modified glass-ionomer cement is often used for implant-supported crowns, prostheses, and all-ceramic restorations. However, available data on the impact of cement types on the fracture resistance of implant-supported monolithic restorations with reduced occlusal thickness is insufficient.

This in vitro study aimed to assess the effect of reduced occlusal thicknesses and cement types on the fracture resistance of implant-supported monolithic zirconia molar crowns subsequent to dynamic loading and thermal cycling aging. The following hypotheses were examined: (1) There is no diversity among the fracture resistance of monolithic zirconia crowns with different occlusal thicknesses, and (2) the type of cement does not influence the fracture resistance of monolithic zirconia crowns.

MATERIALS AND METHODS

Sixty identically shaped implant-supported zirconia maxillary molar crowns were divided into 6 groups (n = 10) according to two study factors: occlusal thickness (0.5, 1.0, and 1.5 mm) and cement type (resin cement and resin-modified glass-ionomer cement). The groups were classified as follows (occlusal thicknesses of the crowns are given in parentheses): Group P0.5, crowns (0.5 mm) cemented with Panavia F; Group KC0.5, crowns (0.5 mm) cemented with Ketac Cem Plus; Group P1, crowns (1 mm) cemented with Panavia F; Group KC1, crowns (1 mm) cemented with Ketac Cem Plus; Group P1.5, crowns (1.5 mm) cemented with Panavia F; and Group KC1.5, crowns (1.5 mm) cemented with Ketac Cem Plus. In this study, the sample sizes were determined according to the previous studies.

First, 60 implant analogs (Oxy, Biomec; Ti grade 4; Fig 1a) with a diameter of 5.5 mm and a length of 14 mm were inserted in an autopolymerizing acrylic (Meliodent, Heraeus Kulzer). The analogs were placed in resin with an angulation of 90 degrees to the vertical plane to make the dynamic loading of the samples uniform, using a metal cover. Then, the prefabricated titanium abutments (Ti grade 4; diameter: 5.5 mm; length: 9.0 mm, internal hexagonal length: 2.2 mm; Oxy, Biomec) were fastened to their analogs with titanium screws by a torque of 30 Ncm in accordance with the manufacturer’s instructions. The torque wrenches were used two times. After 10 minutes, the same torque force was repeated for the loss of preload. Teflon tape was put into screw cavities, and a fluid composite (Filtek Ultimate; #880009, 3M ESPE) was used for filling.

For the manufacture of 60 crowns that had an identically shaped molar maxillary form from zirconia block (BruxZir #B2008925, Glidewell Direct), CAD/CAM software (3Shape D700 Dental System) was used (Figs 1b and 2). The external shape (width of 7.5 mm and height of 14 mm) of the crowns was standardized. The cement space between the crown and abutment was set as 40 μm using CAD/CAM software. For every abutment, the internal designs of the crowns were redone for a precise fit, and chamfer margin was used (Fig 2b). The crowns with occlusal thicknesses of 0.5, 1.0, and 1.5 mm were produced with the CAD/CAM system (Imes-Icore). The occlusal form of the crowns was produced homogeneously in appropriate thickness according to the groups. Then, the crowns were crystallized and glazed (HeraCeram Glaze, Heraeus Kulzer) considering the manufacturer’s suggestion.

Each thickness group (n = 20) was divided into two subgroups for cementation with resin (Panavia F2.0, #41245, Kuraray) and resin-modified glass-ionomer cement (Ketac Cem Plus, #N661322, 3M ESPE) cement. The abutments were rinsed with an ethanol (Sigma Aldrich) before cementation, and no additional primer was used on the implant surface. Before luting, the inside walls of the crowns were cleaned with ethanol (Sigma Aldrich) and sandblasted with 110 μm Al2O3 (#1699969, Renfert) at 2 bars and from 5 cm with a 90-degree angle for 15 seconds. Then, the inside surfaces were rinsed off for 20 seconds. Crowns were cemented on their own die using a resin cement (Panavia F2.0) and a resin-modified glass-ionomer cement (Ketac Cem Plus). Cementation was achieved by the chewing simulator (SD Mechatronik Chewing Simulator CS-4.2, Willytech) under 50-N constant pressure for 5 minutes. After excess luting material was removed, Oxyguard (Kuraray) was applied around the margin for Panavia F2.0 cement for 3 minutes (Fig 3), and light-cured (Elipar S10, 3M ESPE) from the labial and palatal directions for 30 seconds to photopolymerize each cement.

The samples were kept at 37°C for 24 hours before the dynamic loading test. In a chewing simulator (Chewing Simulator CS-4, SD Mechatronik), 1.2 × 106 loading cycles with 70 N and 1.6 Hz were applied to the samples to simulate the chewing equivalent to 5 years of clinical service (240,000 to 250,000 masticatory cycles in the chewing simulator coincide to 1 year of clinical use). As an antagonist, a stainless steel ball (7-mm diameter) with 20 mm/s downward speed hit the middle of the occlusal surface of the maxillary molar crowns while moving back and forth a distance of 0.7 mm with a speed of 20 mm/s. All specimens were checked two times a day for failure during the dynamic loading. Following these tests, the samples were examined using stereomicroscopy (Carl Zeiss) to find fracture or crack of the restoration or loosening of the screw defined as a failure with a magnification of x12.5. Then, all surviving specimens were subjected to thermocycling from 5°C to 55°C with a 30-second...
dwellling time for 5,000 cycles by using a thermocycler
(Esetron Smart Robotechnologies).25,37,38 At the end of
the test, the specimens were checked using the stereoo-
microscope (Carl Zeiss) on ×12.5 magnification.

The surviving specimens without ceramic and
abutment fracture or screw loosening or any other de-
formation after aging were evaluated under compres-
sive load utilizing a universal test machine (Lloyd-LRX,
Lloyd Instruments). A 7-mm stainless steel spherical
tip was centrally placed on the surface of the crown
with a 0.5-mm/min crosshead speed. Tinfoil (0.5-mm
thick) was located on the crowns to distribute the
stress (Fig 4). Compressive loading continued until
failure, and the fracture loads were noted with the
help of software.

The failure mode for each specimen was evaluated
with a magnification of ×12.5 using a light microscope
(Carl Zeiss). Failure types were categorized as equal
parts, uneven parts, and multifragmentary fractures as
done in the previous studies.17,31,33
The Shapiro-Wilk test for normal distributions and the one-way analysis of variance (ANOVA) and the Duncan post hoc test for fracture value analysis were used. The two-way ANOVA and the Fisher Least Significant Difference (FLSD) test were used to evaluate the interaction between the occlusal thicknesses of the crowns and the cement types (α = .05 for all tests). Data were analyzed by SPSS Statistics V22.0 (IBM).

**RESULTS**

All samples survived without showing crown fracture, screw loosening, or screw breakage after aging. The data obtained displayed normal distributions (skewness = 0.808, kurtosis = –0.949).37 The one-way ANOVA test exhibited significant differences between the groups (df = 59, sum of squares = 109,087,965.4, F = 139.326, P < .001). Table 1 displays the mean fracture values and SDs of the groups. The mean maximum failure load values ranged from 1,197.1 ± 65.8 N for group KC0.5 to 4,212.2 ± 501.2 N for group P1.5. The two-way ANOVA test showed that crown thickness (P < .001) and cement type (P < .01) affected the fracture resistance, and no interaction occurred between the two variables (Table 2). The Duncan test indicated that the 1.5-mm-thick crowns had significantly higher fracture load than the crowns with a thickness of 0.5 mm and 1 mm (P < .001). A significant difference was not observed in the mean maximum fracture load between the 1.5-mm-thick crowns luted with resin cement and glass-ionomer cement (Table 1). The lowest fracture strengths were found for the crowns cemented with glass-ionomer cement and with occlusal thicknesses of 0.5 and 1 mm. Meanwhile, significant differences were not detected among groups KC0.5, P0.5, and KC1. Monolithic zirconia crowns with 0.5-mm and 1-mm occlusal thicknesses showed equal parts and bifragmented fractures, whereas the specimens with 1.5-mm occlusal thickness demonstrated multifragmentary fractures. All fractures observed were complete-type fractures and originated from the occlusal region (Fig 5).

**DISCUSSION**

Monolithic zirconia is an alternative restoration material due to its high strength, biologic characteristic, esthetic, and low wear of the opposite enamel for implant-supported restorations.2,3,13 It also reduces the considerable clinical problems that arise from the fracturing of ceramic veneers and zirconia frameworks, especially in implant prostheses with insufficient interarch distance.2,3,13,33 In the present study, occlusal thickness and resin type that could affect the fracture resistance of implant-supported posterior monolithic...
Zirconia crowns were evaluated after dynamic loading and thermal cycling. The outcome of the study refutes the first hypothesis that suggests that there is no significant difference among the fracture resistance of monolithic zirconia crowns with different occlusal thicknesses. Fracture resistance of the monolithic zirconia crowns with an occlusal thickness of 1.5 mm was found to be significantly higher than the crowns with occlusal thicknesses of 1 mm and 0.5 mm ($P < .001$).

In restorative processes, especially when ceramic is used, it is desirable to have an interocclusion distance of 1.5 to 2 mm. Zirconia thickness has been shown to affect the fracture resistance of restorations. Most of the studies on occlusal thickness and fracture strength have been performed on human teeth and polymeric materials. Only a few studies have been performed on implant-supported restorations. It has been found that the fracture resistance of monolithic zirconia molar crowns on human and/or plastic teeth using different occlusal thicknesses is affected by thickness. In those studies, 0.5-, 0.7-, and 1-mm-thick crowns have been frequently evaluated with or without an in vitro aging procedure. They found that the fracture load range was 5,558 ± 522 N for 0.5-mm-thick crowns and 7,542 ± 351 N for 1-mm-thick crowns. They concluded that monolithic zirconia crowns that have 0.5-mm occlusal thickness are suitable in the molar region due to their fracture resistance. In this study, fracture strengths of implant-supported monolithic molar crowns following dynamic loading and thermal cycling aging were found to be 1,198 to 1,354 N, 1,197 to 1,852 N, and 4,015 to 4,212 N for 0.5-mm, 1-mm, and 1.5-mm occlusal thicknesses, respectively. These values were lower than the studies conducted on human or plastic teeth with reduced occlusal thickness. These differences may be attributable to dissimilar modulus of elasticity among implant abutments, human teeth, and plastic teeth, and variables of aging procedures such as dynamic loading and thermal cycling.

The studies that compare fracture resistance of crowns have reported that physiologic occlusal forces that formed in the posterior area range from 250 to 900 N. Meanwhile, it is known that the forces on implant restorations are higher than natural teeth. In this study, all samples displayed failure loads over 1,025 N (minimal value is shown in Table 1) after aging. According to the findings of the present study, it can be said that the crowns in the posterior region with reduced occlusal thickness can withstand physiologic occlusal forces. However, clinical patient-related factors, for instance, increased occlusal forces caused by parafunctions, should be evaluated, and materials should be chosen accordingly.

In the literature, there are studies on implant-supported zirconia crowns with different occlusal thickness and fracture resistance. In one study, zirconia copings with different thicknesses (from 0.4 to 0.8 mm) on implant analogs were evaluated with cycling loading. The results of that study showed that zirconia thickness had a significant impact on the fracture resistance, and 0.7-mm-thick zirconia crowns had a high fracture resistance. In contrast to the present study, the crowns of that study were made as a copings. In addition, maximum fracture resistance and thermal cycling were not employed in that study. Another study that investigated the fracture resistance of implant-supported monolithic zirconia molar crowns found that the fracture strength was 6,015 N for 3.5-mm occlusal thickness. In contrast to the present study, reduced occlusal thickness of the crown was not studied, and the aging process was not employed in that study. The fracture being higher than the present study can be attributable to these factors. Another study compared the fracture resistance of alternative CAD/CAM materials on molar implant-supported crowns, and found that the fracture resistance was 4,817.8 ± 1,600 N for 1.5-mm-thick monolithic zirconia crowns after thermal cycling and mechanical loading. The results are consistent with the present study in terms of the fracture resistance of 1.5-mm-thick monolithic zirconia crowns (4,212.2 ± 501 N). Panavia resin cement was used for luting in both studies.

It is widely known that the cement type has a crucial role in the fracture strength of all-ceramic restorations. Research has proven that adhesive cementation of zirconia crowns improves fracture resistance, and in many studies, resin cement was used for evaluating in vitro performance of implant-supported restorations. Studies also showed that resin-modified glass-ionomer cements are used in implant-supported metal crowns to obtain high retention. However, the impact of cement type on the fracture resistance of implant-supported monolithic zirconia crowns with reduced occlusal thickness has not been reported yet. Therefore, in this study, resin cement (Panavia F) and resin modified glass-ionomer cement (Ketac Cem Plus) were used for luting the crowns. The results refute the hypothesis that suggests that the kind of cement does not influence the fracture resistance of implant-supported monolithic zirconia crowns. Resin cement displayed a higher fracture resistance than resin-modified glass-ionomer cement in all groups. Interestingly, statistically significant distinctions were observed only in the 1-mm occlusal thickness group (1,852 N and 1,197 N for Panavia F cement and Ketac Cem Plus, respectively). This thickness can be noted as a crucial thickness for zirconia crowns that can be strengthened by choosing a suitable cement type. In addition, two-way ANOVA exhibited that the occlusal thickness affects the fracture load significantly.
(P < .001), rather than the cement type (P < .01). These results suggest that adequate occlusal thickness (1.5 mm) of monolithic zirconia crowns enhances the mechanical strength and removes the need for cement support. This evidence is in line with that of earlier in vitro studies reporting that the fracture loads for zirconia crowns with sufficient occlusal thickness were not influenced by the cement type.13,14

Changes in the physical characteristics of a restoration that result from chewing load and thermal changes after a period of clinical use are important. In this study, all samples were subject to 1.2 x 10⁶ loading cycles under 70-N load in a mastication simulator. This loading is equivalent to approximately 5 years of clinical use5,24,29. 240,000 to 250,000 masticatory cycles in a chewing simulator is equivalent to approximately 1 year of clinical use.34,36 All samples were also subjected to thermocycling from 5ºC to 55ºC for a total of 5,000 cycles before mechanical tests.38,39

In terms of fracture type, zirconia crowns that had 0.5-mm occlusal thickness were fractured into two almost-equal parts from the occlusal region, regardless of their cement types. However, two uneven part fractures at the occlusal area were seen in 1-mm-thick crowns, and multifragmentary fractures were observed in 1.5-mm-thick crowns. Similarly, a previous study showed that multifragmentary fractures are most likely seen in increased occlusal thickness since the crowns with higher occlusal thickness break under higher load due to their increased breaking resistance.8 In the present study, a multifragmentary fracture pattern could also explain the higher SD of the groups with 1.5-mm occlusal thickness compared with the others. In a study on crown fracture types of monolithic zirconia crowns with occlusal thicknesses of 0.3, 0.5, 0.7, 1.0, and 1.5 mm, the occlusal region was shown as the fracture initiation site, and a correlation between occlusal thickness and multiple fragmented fractures was shown.7 In various studies comparing monolithic zirconia crown fracture types, the results were similar to the outcome of the present study, and fractures originated from the occlusal surface.1–3,5,15,16

Some other variables, such as abutment material and diameter, occlusal morphology (occlusal groove and cusp height), opposite tooth arch, and interocclusal distance, could also affect the formation of fracture in implant-supported monolithic zirconia crowns.6,12,15,40 Titanium abutments have higher fracture resistance than other abutment materials, and 4.5- to 5.5-mm abutment diameters have commonly been preferred in the posterior region.2–4,26,31 The survival rate of implant-supported crowns is affected by occlusal morphology. Studies emphasize that steep cusp inclines, wide occlusal tables, and premature contacts should be avoided in implant restorations.6,12,15,40 Taking into consideration the aforementioned factors, titanium abutments with a 5.5-mm diameter were chosen, and a flat occlusal surface was examined in the present study.

In this study, different occlusal thicknesses and cement types, higher dynamic loading forces, different loading cycles, and monolithic zirconia prostheses could be used. These can be considered as the limitations of the study. Further in vitro studies comparing different occlusal thicknesses and cement types may provide additional insights to demonstrate suitability for use in the clinic setting. In addition, clinical studies are required based on the results of in vitro studies.

CONCLUSIONS

Implant-supported monolithic zirconia molar crowns with reduced occlusal thickness as low as 0.5 mm can withstand physiologic occlusal forces. However, clinical patient-related factors, such as increased occlusal forces caused by parafunctions, should be considered. Crowns with an occlusal thickness of 1.5 mm had the highest fracture resistance (4,212.2 ± 501.2 N) irrespective of the cement type. Cementation with resin cement can be recommended for implant-supported monolithic zirconia molar crowns with occlusal thicknesses of 1 mm and 0.5 mm to achieve higher fracture load values.

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