

Effect of Different Cement Thicknesses on Fracture Resistance of Monolithic Full Anatomic Zirconia Crowns: An In Vitro Study

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ABSTRACT

Background: Zirconia has become widely used in all-ceramic restorations because of its mechanical properties and improved esthetics compared with metal-based restorations. Concerns about Zirconia-based prostheses have historically been focused on the risk of chipping and veneering porcelain. Monolithic zirconia restorations eliminate the risk of veneering porcelain chipping commonly associated with layered restorations. In addition, the use of Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM) in the production of these crowns has improved restoration quality by providing a higher degree of material homogeneity [1, 2].

Objective: To evaluate the effect of different digitally set cement thicknesses (30 μm , 60 μm , and 90 μm) on the fracture resistance of CAD/CAM monolithic zirconia crowns.

Methods: Thirty-six monolithic zirconia crowns were milled via CAD/CAM and divided into three groups based on cement thickness: 30 μm (Group A), 60 μm (Group B), and 90 μm (Group C). Specimens were loaded vertically in a universal testing machine at 1 mm/min with a 10 N preload until fracture, and forces were recorded in Newton.

Results: The mean fracture resistance values were 4305.3 N for Group A, 3696.5 N for Group B, and 4233.4 N for Group C. No statistically significant difference was found among the groups ($p = 0.144$).

Conclusion: Within the limitations of this in vitro study, cement thicknesses ranging from 30 μm to 90 μm did not significantly affect the fracture resistance of monolithic zirconia crowns.

Keywords: zirconia; monolithic crowns; cement thickness; fracture resistance; CAD/CAM materials

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INTRODUCTION

In contemporary dental practice, the continuous advancement and evolution of dental materials, as well as digital fabrication technologies, have had a profound and substantial impact on restorative practices. The incorporation of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems has transformed the fabrication of fixed dental prostheses, especially those utilizing ceramic.¹ Zirconia has become one of the most widely used ceramic materials in restorative dentistry because of its excellent mechanical properties, biocompatibility, and esthetics. The introduction and continuous development of CAD/CAM technology have enhanced the fabrication and clinical application of zirconia restorations.²

Zirconia, particularly yttria-stabilized tetragonal zirconia polycrystals (Y-TZP), is distinguished by outstanding mechanical properties comparable to those of stainless steel. Recognized as the strongest and toughest dental ceramic currently available, Y-TZP typically exhibits a flexural strength between 900 and 1200 MPa and a fracture toughness of 9-10 MPa.^{3,4} These mechanical characteristics are primarily attributed to its unique phase transformation to toughening mechanism. Under stress, the metastable tetragonal grains transform into the monoclinic phase, process that includes local compressive stress around crack tips and effectively impedes crack propagation.^{5,6}

The development of monolithic zirconia crowns has significantly advanced prosthodontic treatment, directly addressing the chipping risk associated with layered restorations.^{7,8}

This advancement has made monolithic Zirconia a desirable option, especially for high-stress posterior applications, with studies showing that even crowns with minimal thicknesses (e.g., 0.5 mm) can withstand mean fracture loads exceeding 5000 N, significantly outperforming other monolithic ceramic options such as lithium disilicate.^{9,10}

In addition to the inherent strength of the material, the interfaces between the crown, cement, and abutment play a critical role in determining the overall fracture resistance of all-ceramic crowns. A weaker bond at these interactions can significantly compromise fracture resistance.^{11,12} Consequently, precise tooth preparation, accurate impressions, and meticulous fabrication are essential for controlling the cement thickness and ensuring the long-term success and durability of the restoration.¹³

The cement thickness, defined as the space be-

tween the prepared tooth surface and the internal surface of the crown, is a critical parameter in restorative dentistry. Achieving an optimal and uniform cement thickness is essential for proper crown seating, even occlusal force distribution, and the reduction of stress concentrations that could lead to fracture.¹⁴ An inadequate thickness may impair cement flow, cause air entrapment, hinder complete polymerization, and ultimately lower bond strength and mechanical stability.^{15,16} On the other hand, an excessive cement thickness can also compromise stress distribution and fracture resistance by producing a thicker, and potentially weaker, cement layer.^{14,17} The introduction of CAD/CAM technologies now enables precise control over this key parameter through digital die spacer settings.

Although the significance of the cement thickness is well recognized, the specific effect of varying cement thickness on the fracture resistance of monolithic zirconia crowns remains a subject of ongoing research. Some studies suggest that the impact may vary depending on the material type and experimental conditions.^{18,14} Accordingly, this *in vitro* study aims to evaluate the influence of different cement thicknesses (30 μm , 60 μm , and 90 μm) on the fracture resistance of monolithic full anatomic zirconia crowns fabricated using a CAD/CAM system and tested under a universal load testing machine.

Although monolithic zirconia crowns exhibit excellent mechanical properties and high fracture resistance, the effect of different cement thicknesses on their fracture resistance remains unclear. CAD/CAM systems permit accurate adjustment of cement space; however, evidence regarding the optimal cement thickness for maintaining the mechanical performance of zirconia restorations is still limited. Previous studies have reported inconsistent findings regarding the influence of cement thickness on stress distribution and fracture resistance. Therefore, further investigation is required to evaluate the effect of different cement thicknesses on monolithic zirconia crowns.

Aim of the Study

The aim of this *in vitro* study was to evaluate the effect of different cement thicknesses (30 μm , 60 μm , and 90 μm) on the fracture resistance of monolithic full anatomic zirconia crowns fabricated using a CAD/CAM system, tested under a universal load testing machine.

METHODS

Materials: (One mandibular first molar extracted for periodontal reasons was used as the reference model. A local ethics committee in the Prosthodontic Department, University of Hawler College of Dentistry, authorized the study and assigned it scientific form number Pros 24203. The tooth was stored in deionized water throughout the study to prevent dehydration, Shifner Block, Zirconia Block (Upcera, China), Self-Adhesive Dental Cement (Escem, China).

Equipment: Dental surveyor, Hand piece (NSK CONTRA ANGLE HANDPIECENSK - Model no - NAC-EC, Order no - Y110148. NON -Optic, Japan), preparation diamond burs taper 4 Germany, Medit Scanner (Medit i600, Korea), Zirkozahn M1, Italy 2014, Zirkonofen 600, Italy 2014, universal load testing machine (GOTECH A1-3000M, China).

The methodology of this study was designed to include tooth preparation, crown design, crown fabrication, cementation of the crowns, and testing of the samples.

Design of the study

Sample size calculation was performed using G*Power software version 3.1.9.4.

The significance level was set at 5% and the power of the test was 80%. Using CAD/CAM, 36 monolithic full anatomic crowns were fabricated and divided into three groups: Group A, with 12 samples and a cement thickness of 30 μm ; Group B, with 12 samples and a cement thickness of 60 μm ; and Group C, with 12 samples and a cement thickness of 90 μm . These crowns were cemented onto titanium abutments that were replicated from a natural mandibular first molar using an intra-oral scanner.

Tooth preparation procedure

One mandibular first molar extracted from a 64-year-old patient for periodontal reasons was used as the reference model for this in vitro study. A local ethics committee in the Prosthodontic Department, University of Hawler College of Dentistry, authorized the study and assigned it scientific form number Pros 24203. Throughout the study, the tooth was stored in deionized water to prevent dehydration.

The tooth was mounted on a dental surveyor to ensure proper alignment and prepared using an NSK contra-angle handpiece (Model NAC-EC, Japan) with a tapered diamond bur (Taper 4, Germany). The preparation followed recommended guidelines

for zirconia restorations, including 2 mm functional occlusal reduction, a 1 mm chamfer finish line, 1.5 mm circumferential axial reduction, 4 mm occluso-gingival height, and a 6° convergence angle.¹² The prepared tooth was used to fabricate 36 standardized titanium abutments from Shifner blocks (Germany) using a wet milling machine (Redon TR60, Turkey). These abutments were subsequently scanned with an intraoral scanner (Medit i600, Korea) to fabricate 36 monolithic full-anatomic zirconia crowns for testing.

Crowns Design

An experienced Exocad laboratory technician designed the crowns using software registered in the Zirkozahn company design library. The crowns were designed into three groups with different cement thicknesses, with Group A having 30 μm , Group B having 60 μm , and Group C having 90 μm . The crowns were designed with an occlusal thickness of 2 mm and a buccolingual thickness of 2 mm. All crown characteristics were standardized, except for the thickness of the cement.

Crown Fabrication

The crowns were fabricated using a zirconia block (Upcera, China) milled in a milling machine (Zirkozahn M1, 2014) according to the following specifications: 30 μm cement thickness for group A, 60 μm cement thickness for group B, and 90 μm cement thickness for group C. According to the manufacturer's recommendations, the crowns were sintered in (Zirkonofen 600, Italy, 2014) for 8 hours at 1500° C and then allowed to reach room temperature. The crowns were subsequently glazed with the same company's glazed material for twenty minutes at 920° C in the same furnace (Zirkonofen 600, Italy, 2014).

Cementation of the samples

According to the manufacturer's recommendations, the resin cement was applied to the internal surface of the crowns using self-adhesive universal resin cement (Escem, China). Initial seating was achieved using finger pressure. A standardized load of 5 kg was applied for 5 minutes using a specimen-holding cementation apparatus prior to testing. All specimens were stored in distilled water at room temperature for 24 hours.

Testing the samples

The samples were tested in a universal load testing machine (GOTECH A1-3000M, China) after stabilizing each sample (monolithic full anatomic crown for each group) on the machine. Specimens were subjected to vertical loading in a

universal testing machine using a 5-mm-diameter spherical steel indenter at a crosshead speed of 1 mm/min with a 10-N preload until fracture occurred. The fracture load was recorded in Newton (N) by connected computer software.



Figure 1. Ten monolithic full anatomic zirconia crowns after cementation and before testing



Figure 2. The universal load testing machine was used while testing the monolithic full anatomic zirconia crowns

Statistical analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS, version 26). The normality of the data was assessed using the Shapiro–Wilk test, which indicated that the data were normally distributed ($p > 0.05$). Homogeneity of variances was evaluated using Levene’s test, which showed no significant differences between groups ($p > 0.05$).

All samples were independent. Accordingly, a parametric test (one-way analysis of variance, ANOVA) was conducted to compare the mean fracture resistance among the three groups. Post hoc analysis using Tukey’s test was performed for pairwise comparisons. A p -value ≤ 0.05 was considered statistically significant.

Effect size (eta-squared, η^2) was calculated to assess the magnitude of differences between groups.

RESULTS

The normality of data was tested using the Shapiro–Wilk test. Its results showed that the data was normally distributed. Since the data were normally distributed, mean and standard deviation were used to describe the results; however, median values showed a similar distribution pattern across the study groups. The mean fracture resistance value for Group A was 4305 N, and that of Group B was 3696.5 N, whereas Group C demonstrated a mean fracture resistance value of 4233.4 N. No statistically significant difference was observed among the groups ($p = 0.144$) (Table 1). The effect size was small ($\eta^2 = 0.08$), indicating a weak magnitude of difference.

Table 1. Fracture Resistance by Cement Thickness

95% Confidence Interval for Mean						
	N	Mean force (Newton)	SD	Std. Error	Lower Bound	Upper Bound
Group A	12	4305.3	1018.1	293.9	3658.4	4952.2
Group B	12	3696.5	595.5	171.9	3318.1	4074.9
Group C	12	4233.4	739.0	213.3	3763.9	4703.0
Total	36	4078.4	827.5	137.9	3798.4	4358.4

*Calculated by One-way analysis of variance (ANOVA), p -value = 0.144

DISCUSSION

This study examined the effect of cement thickness (30 μ m, 60 μ m, and 90 μ m) on the fracture resistance of CAD/CAM-fabricated monolithic zir-

conia crowns. The results demonstrated no statistically significant differences among the groups ($p = 0.144$), consistent with Mohamed et al. (2020)⁶ and Rahimi et al. (2024).⁸

All groups exhibited high fracture resistance values (3696.5–4305.3 N), which exceed the maximum posterior masticatory forces of approximately 400–900 N. This agrees with Baixauli-López et al. (2021),⁵ who reported excellent survival rates of monolithic zirconia crowns, and Kim et al. (2022),⁹ who confirmed zirconia crowns withstand loads well above functional requirements. Compared with lithium disilicate crowns, which show lower fracture resistance under similar conditions (Ahn et al., 2020),¹⁴ zirconia demonstrates superior mechanical performance.

The high fracture resistance observed across all groups may be attributed to zirconia's transformation-toughening mechanism, Rezende et al. (2017)¹⁸ showed cement space variations had limited impact on stress distribution in Y-TZP crowns, while Abad Coronel et al. (2023)¹⁶ confirmed translucent zirconia maintains high fracture resistance even with CAD/CAM milling variations. These findings reinforce zirconia's robustness compared to other ceramics.

Although Group B (60 µm) exhibited a slightly lower mean fracture resistance than Groups A and C, this difference was not statistically significant. Minor variations may be related to internal adaptation inconsistencies, cement flow behavior, or localized stress concentrations during loading. Ahn et al. (2020)¹⁴ suggested that cement thickness can influence stress distribution patterns; however, when cement spaces remain within clinically acceptable limits, the effect on fracture resistance appears minimal. From a clinical perspective, the findings of this study indicate that CAD/CAM systems allow flexibility in selecting cement spacer settings between 30 µm and 90 µm without compromising the structural integrity of monolithic zirconia crowns. This observation is supported by Farag et al. (2021),¹³ who emphasized that moderate variations in internal spacer thickness do not significantly affect the mechanical performance of ceramic restorations, provided that internal adaptation remains within acceptable limits.

Despite the promising results, several limitations must be acknowledged. First, the *in vitro* nature of the study does not fully replicate intraoral conditions, where factors such as thermal cycling, humidity, saliva, and cyclic loading may influence long-term performance. Second, titanium abutments were used instead of natural teeth, which may alter stress distribution due to differences in elasticity. Third, the actual cement thickness after

seating was not microscopically verified and may differ slightly from the digitally assigned values. Additionally, only one type of resin cement was used, limiting the generalizability of the findings across different luting agents.

Future research should incorporate thermomechanical aging, evaluate multiple cement types, and assess long-term fatigue behavior under simulated oral conditions. Investigating the interaction between cement thickness, crown design, and abutment material may also provide deeper insight into optimizing zirconia restoration performance.

CONCLUSION

Within the limitations of this *in vitro* study, variations in cement thickness between 30 µm and 90 µm did not have a statistically significant effect on the fracture resistance of monolithic zirconia crowns. All tested crowns demonstrated fracture resistance values exceeding normal posterior masticatory forces, indicating adequate mechanical performance.

These findings suggest that minor variations in CAD/CAM cement space settings within this range may be clinically acceptable. However, caution should be taken when interpreting the results due to the laboratory nature of the study. Further studies incorporating thermomechanical aging, different luting agents, and long-term clinical evaluation are recommended.

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Conflict of Interest

The authors declare no conflicts of interest.

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