

Effect of Crown Thickness and Abutment Taper on the Fracture Resistance of Monolithic Zirconia Crowns: An In Vitro Study

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Review began 10/03/2026

Review ended 10/11/2026

Published 10/21/2026

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DOI: 10.7759/cureus.118339

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Abstract

Introduction: Monolithic zirconia permits conservative tooth preparation while providing high mechanical strength. However, the effects of reduced crown thickness and abutment taper on fracture resistance require further evaluation. This study aimed to evaluate the effects of monolithic zirconia crown thickness and abutment taper on fracture resistance and determine whether these factors influence fracture load.

Materials and methods: This in vitro study evaluated 48 standardized typodont dies restored using computer-aided design/computer-aided manufacturing (CAD/CAM)-fabricated monolithic zirconia crowns. The crowns were divided according to thickness into 0.5 mm, 1.0 mm, and 1.5 mm groups, with each thickness further subdivided into 5° and 10° abutment taper groups (n=8 per subgroup). The specimens were cemented using dual-cure resin cement, thermocycled for 5,000 cycles between 5°C and 55°C, and subjected to compressive loading with a 4 mm spherical indenter at 1 mm/min until fracture. Fracture load was analyzed using two-way analysis of variance, independent-samples t-tests, and Tukey's honestly significant difference post hoc test.

Results: The mean fracture load increased progressively with crown thickness. For the 5° taper, the mean fracture loads were 1,498 N, 2,429 N, and 3,612 N for 0.5 mm, 1.0 mm, and 1.5 mm crowns, respectively, and the corresponding values for the 10° taper were 1,018 N, 2,124 N, and 3,212 N. Crown thickness significantly affected fracture load ($p < 0.001$; partial $\eta^2 = 0.899$), as did taper ($p < 0.001$; partial $\eta^2 = 0.310$). The thickness $\times$ taper interaction was not statistically significant ($p = 0.735$). Tukey's comparisons showed significant differences among all thickness levels ($p < 0.001$).

Conclusion: Greater zirconia thickness and lower abutment taper were associated with higher fracture resistance under the tested conditions. These findings highlight the importance of both crown thickness and preparation geometry in optimizing the mechanical performance of monolithic zirconia crowns. Further clinical studies using fatigue loading and more representative oral conditions are warranted.

Categories: Dentistry

Keywords: computer-aided design, dental crowns, dental materials, dental stress analysis, zirconium oxide

Introduction

The increasing use of computer-aided design and computer-aided manufacturing (CAD/CAM) has expanded the application of monolithic zirconia in fixed dental restorations [1]. Zirconia offers favorable mechanical properties and high fracture resistance, making it particularly attractive for posterior restorations exposed to substantial occlusal forces. Advances in zirconia composition and manufacturing have also improved its optical properties and enabled the fabrication of full-contour restorations without the need for a veneering ceramic layer [2,3].

Despite these advantages, adequate restorative thickness remains an important consideration when preparing zirconia crowns. Excessive occlusal reduction may compromise the preservation of tooth structure, whereas insufficient reduction can result in restorations with inadequate material thickness [3,4]. This issue is particularly relevant when interocclusal space is limited. Previous investigations have demonstrated that fracture resistance generally increases with increasing zirconia thickness; however, the minimum thickness capable of withstanding functional occlusal forces remains an area of continuing investigation [4,5]. An in vitro study demonstrated a progressive increase in fracture resistance from 1.0 mm to 2.0 mm occlusal thickness and suggested that even a 1 mm monolithic zirconia crown could withstand forces exceeding the commonly reported posterior biting forces [6].

In addition to restorative thickness, the geometry of the prepared abutment may influence the mechanical

How to cite this article

Jayakumar A, Elangovan S K, Raju V (October 21, 2026) Effect of Crown Thickness and Abutment Taper on the Fracture Resistance of Monolithic Zirconia Crowns: An In Vitro Study. Cureus 18(10): e118339. DOI 10.7759/cureus.118339

performance of the crown. The degree of abutment taper can affect the amount and distribution of restorative material and may consequently alter the load-bearing capacity of monolithic zirconia restorations [7]. This in vitro study evaluated the effects of monolithic zirconia crown thickness (0.5 mm, 1.0 mm, and 1.5 mm) and abutment taper (5° and 10°) on fracture resistance and examined the interaction between these factors. The primary hypothesis was that crown thickness and abutment taper would significantly affect fracture resistance, with a possible interaction between them.

Materials And Methods

Study design and setting

This in vitro study was conducted in the Department of Prosthodontics in March 2024 at the Karpaga Vinayaga Institute of Dental Sciences, Chengalpattu, India. The experimental protocol involved 48 standardized typodont dies prepared to simulate mandibular molar abutments. The specimens were allocated according to two experimental factors: crown thickness at three levels (0.5 mm, 1.0 mm, and 1.5 mm) and abutment taper at two levels (5° and 10°). Thus, six experimental subgroups were generated, with eight specimens in each subgroup. Ethical approval was not required for this study because it was an in vitro experimental investigation conducted exclusively using standardized typodont dies and did not involve human participants, human tissues, extracted human teeth, or animal subjects.

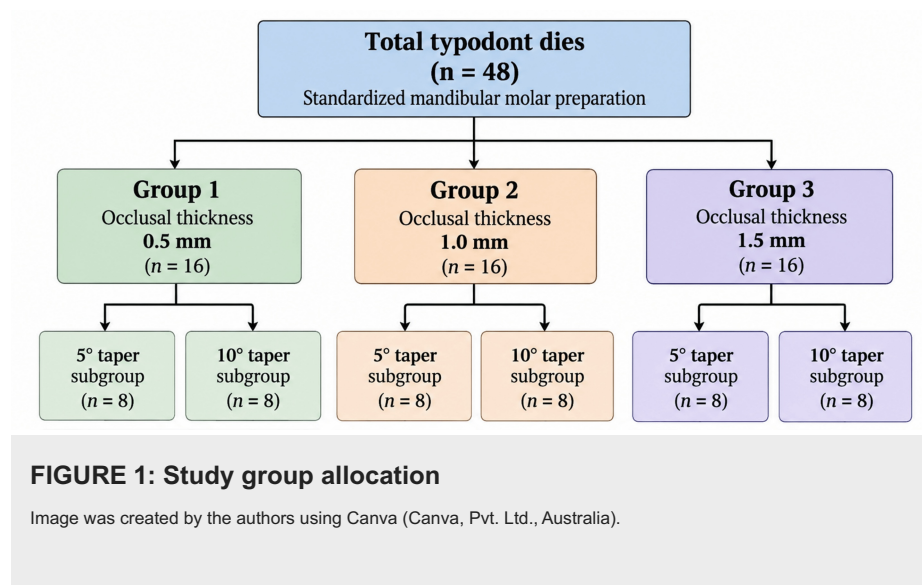
Sample size calculation

The sample size was determined a priori using GPower software (version 3.1; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The calculation was based on an F-test for analysis of variance (ANOVA) with fixed effects and omnibus comparison of multiple groups. A medium effect size (Cohen's $f=0.50$), significance level (α) of 0.05, and statistical power of 80% ($1-\beta=0.80$) were specified [8]. The calculations yielded a total sample size of 48 specimens. Accordingly, 16 specimens were assigned to each crown thickness group (0.5 mm, 1.0 mm, and 1.5 mm), and each thickness group was further divided equally according to the abutment taper into 5° and 10° subgroups, resulting in eight specimens per subgroup.

Experimental specimens and standardization

The 48 typodont dies were prepared manually according to the intended experimental configurations. The crown designs were developed using exocad DentalCAD, with the prescribed 5° and 10° taper configurations incorporated into the digital design. The specimens were allocated to six experimental subgroups, with eight specimens per subgroup. Manual preparation was performed to reproduce the specified abutment configurations while minimizing anatomical and dimensional variability between specimens.

The specimens were categorized into three groups according to the planned occlusal thickness of the monolithic zirconia crowns. Group 1 consisted of crowns with a 0.5 mm occlusal thickness, Group 2 consisted of crowns with a 1.0 mm occlusal thickness, and Group 3 consisted of crowns with a 1.5 mm occlusal thickness. Within each thickness group, specimens were subdivided according to abutment taper into 5° and 10° taper subgroups, with eight specimens in each subgroup (Figure 1).



Crown design and fabrication

The prepared typodont dies were digitized using a Medit T500 laboratory scanner (Medit Corp., Seoul, Republic of Korea), and the resulting digital models were used for crown design using exocad DentalCAD

software (exocad GmbH, Darmstadt, Germany). Monolithic zirconia crowns were designed using a CAD/CAM workflow. Three target occlusal thicknesses were used: 0.5 mm, 1.0 mm, and 1.5 mm. The abutment taper was incorporated into the digital design according to the assigned 5° or 10° preparation configurations. The crowns were fabricated by CAD/CAM milling using Bloomzircon ST White zirconia blanks (Bloomden Bioceramics (Hunan) Co., Ltd., Changsha, Hunan, China), a zirconia material previously used for the fabrication of monolithic CAD/CAM crowns. The milling parameters were standardized across all experimental groups, with crown thickness and abutment taper serving as predefined experimental variables. CAD/CAM fabrication was used to ensure consistent reproduction of the prescribed crown dimensions and minimize the variability associated with manual fabrication.

Standardization of cement space

To obtain a standardized cement film thickness, the typodont dies were coated with a calibrated number of die spacer layers corresponding to a cement space of 0.25 mm. The die spacer was applied uniformly to the dies before digital scanning and crown fabrication so that the internal dimensions of the crowns provided a predetermined cement space. Standardization of the cement space was intended to minimize variations in the seating and cement thickness between the specimens.

Cementation procedure

After fabrication and inspection, each monolithic zirconia crown was cemented to its corresponding typodont die using dual-cure resin cement (Ivoclar SpeedCEM Plus, Ivoclar Vivadent India Pvt. Ltd.). The crowns were seated under a standardized load of 50 Newtons (N) to promote consistent seating and minimize variation in the cement film thickness between specimens. Excess cement was removed after seating, and the specimens were subjected to the manufacturer's recommended setting procedure before subsequent aging and mechanical testing.

Thermocycling procedure

Following cementation, all specimens were artificially aged by thermocycling to simulate the repeated temperature changes encountered in the oral environment. Thermocycling was performed using a Thermocycler THE-1100 (SD Mechatronik GmbH, Feldkirchen-Westerham, Germany) for 5,000 cycles between 5°C and 55°C, with a 30-second dwell time in each bath and a 5-10-second transfer time between baths. The specimens were alternately exposed to cold- and warm-water baths according to the prescribed cycling sequence. Thermocycling was performed uniformly for all specimens before mechanical testing to ensure that each experimental group underwent the same aging protocol.

Fracture resistance testing

After completion of thermocycling, fracture resistance was evaluated using a universal testing machine (STAR Testing System, Model No. STS 248, Mumbai, India). Each specimen was positioned so that the loading point was aligned with the central fossa of the crown. A 4 mm diameter spherical steel indenter was used to apply a compressive load to the occlusal surface. The load was applied at a constant crosshead speed of 1 mm/min until crown or specimen failure occurred. The maximum load recorded immediately before failure was defined as the fracture load and expressed in N. This load-to-failure approach was selected because fracture load provides a direct quantitative measure of the mechanical resistance of monolithic zirconia restorations under controlled laboratory conditions. Similar experimental investigations of monolithic zirconia crowns have used controlled compressive loading until fracture to evaluate fracture resistance.

Outcome assessment

The primary outcome variable was the maximum fracture load. The independent variables were crown thickness (0.5 mm, 1.0 mm, and 1.5 mm) and abutment taper (5° and 10°). Therefore, the principal comparisons evaluated the effects of crown thickness and abutment taper, as well as the interaction between these two factors.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). The distribution of fracture-load data was assessed and confirmed using the Shapiro-Wilk test to evaluate normality, while Levene's test was used to assess the homogeneity of variances. Because the experimental design incorporated two independent factors, a two-way ANOVA was performed to determine the main effects of crown thickness, abutment taper, and their interaction on fracture load. The interaction term assessed whether the effect of crown thickness on fracture resistance differed according to the degree of the abutment taper. Effect sizes were expressed as partial eta squared (η^2p) for ANOVA effects. To evaluate differences between taper levels within each crown thickness category, independent-samples t-tests were performed for the 5° versus 10° taper subgroups at each thickness. Cohen's d was used to quantify the magnitude of these subgroup differences. For comparisons among crown thickness levels, Tukey's honestly significant difference (HSD) post-hoc test was applied following two-way ANOVA, with comparisons

performed after pooling across taper levels as specified in the statistical analysis plan. The effect sizes for these pairwise comparisons are expressed using Cohen's d. A two-sided p-value <0.05 was considered statistically significant.

Results

A total of 48 specimens were evaluated, with eight specimens in each of the six experimental subgroups. The fracture load data demonstrated a progressive increase in fracture resistance with increasing crown thickness. Across both taper configurations, the 1.5 mm crowns exhibited the highest fracture loads, followed by the 1.0 mm and the 0.5 mm crowns (Table 1).

Crown thickness	Abutment taper (degrees)	n	Fracture load, mean ± SD (N)	95% CI of mean (N)
0.5 mm	5°	8	1,498±116	1,401.0-1,595.0
	10°	8	1,018±940	939.4-1,096.6
1.0 mm	5°	8	2,429±315	2,165.6-2,692.4
	10°	8	2,124±245	1,919.2-2,328.8
1.5 mm	5°	8	3,612±495	3,198.1-4,025.9
	10°	8	3,212±411	2,868.4-3,555.6

TABLE 1: Fracture load (N) according to crown thickness and abutment taper

Data are presented as the mean ± SD and 95% CI.

Fracture load is expressed in Newtons (N).

SD, standard deviation; CI, confidence interval

Two-way ANOVA demonstrated that crown thickness had a statistically significant effect on fracture load (p<0.001). The abutment taper was also significantly associated with fracture resistance (p<0.001), whereas the interaction between crown thickness and taper was not statistically significant (p=0.735) (Table 2).

Source of variation	Sum of squares	Degrees of freedom (df)	Mean squares	F-value	P-value	Partial η² (effect size)
Thickness	37,154,232	2	18,577,116	187.18	<0.001*	0.899
Tapering	1,872,300	1	1,872,300	18.86	<0.001*	0.310
Thickness×taper	61,400	2	30,700	0.31	0.735	0.014

TABLE 2: Main effects of crown thickness and abutment taper and their interaction on fracture load

*P-value < 0.05 was considered statistically significant.

Two-way analysis of variance (ANOVA) was used to assess the effects of crown thickness, abutment taper, and their interaction on fracture load.

Subgroup analysis showed that the 5° taper produced significantly greater fracture loads than the 10° taper for the 0.5 mm and 1.0 mm crown thicknesses. However, the difference between the taper configurations was not statistically significant for the 1.5 mm crowns (p=0.100) (Table 3).

Table with 6 columns: Crown thickness, Mean difference (5°-10°), 95% CI of difference, t-value, P-value, Cohen's d. Rows show data for 0.5 mm, 1.0 mm, and 1.5 mm crown thicknesses.

TABLE 3: Comparison of fracture load between abutment taper levels within each crown thickness

*P-value <0.05 was considered statistically significant.
Independent-samples t-tests were used to compare the 5° and 10° abutment taper groups within each crown thickness in millimeters.
CI: confidence interval, N: Newtons

Tukey's post hoc analysis demonstrated statistically significant differences among all three crown thickness levels. Fracture resistance increased significantly with each increase in crown thickness, with significant differences observed between 0.5 mm and 1.0 mm, 1.0 mm and 1.5 mm, and 0.5 mm and 1.5 mm (all p<0.001) (Table 4).

Table with 7 columns: Comparison, Fracture load, mean difference, SE of difference, 95% CI of difference, t-value, P-value, Cohen's d. Rows show pairwise comparisons between crown thickness levels (1.0 mm vs. 0.5 mm, 1.5 mm vs. 1.0 mm, 1.5 mm vs. 0.5 mm).

TABLE 4: Pairwise comparisons of fracture load between crown thickness levels

*P-value <0.05 was considered statistically significant.
Tukey's HSD post-hoc test was used for pairwise comparisons of crown thickness levels pooled across abutment taper groups.
SE: standard errors; CI: confidence interval; HSD: honestly significant difference

Discussion

The present in vitro study demonstrated that both monolithic zirconia crown thickness and abutment taper significantly influence fracture resistance. The crown thickness showed a strong effect on the fracture load, with the resistance progressively increasing from 0.5 mm to 1.5 mm. This finding is consistent with the fundamental mechanical behavior of zirconia restorations, as increasing the material thickness provides greater load-bearing capacity and reduces the likelihood of critical crack initiation and propagation under occlusal loading [6,9]. The progressive increase observed in the present study is also consistent with previous investigations showing a significant relationship between occlusal thickness and fracture load of monolithic zirconia crowns [5,8]. Nakamura et al. [8] reported that occlusal thickness significantly influenced the fracture load, although their study found that even 0.5 mm zirconia crowns demonstrated high fracture resistance.
The clinical significance of this finding is particularly relevant when tooth preservation and limited interocclusal space are of concern. Although thinner zirconia restorations may permit more conservative tooth preparation, the reduction in thickness is accompanied by a reduction in mechanical reserve. The present findings suggest that clinicians should avoid unnecessarily reducing zirconia thickness when adequate restorative space is available, while also recognizing that reduced-thickness monolithic zirconia may remain mechanically viable under appropriate conditions [10]. A previous in vitro study similarly demonstrated significantly greater fracture resistance with increasing occlusal thickness and concluded that reduced-thickness monolithic zirconia could tolerate clinically relevant occlusal forces [4].
In contrast, Sorrentino et al. [11] reported that occlusal thickness did not significantly influence the fracture

resistance of CAD/CAM monolithic zirconia molar crowns, with even 0.5 mm thick crowns demonstrating fracture resistance above physiological occlusal loads. This discrepancy may be attributable to differences in experimental methodology, including zirconia material and processing, crown design, specimen substrate, cementation protocol, aging conditions, and loading configuration. In the present study, the additional influence of abutment taper and the use of standardized typodont dies may also have contributed to the observed thickness-dependent differences in fracture resistance.

Bolaca and Erdoğan [12] similarly reported that CAD/CAM zirconia crowns demonstrated high fracture resistance even at reduced occlusal thicknesses of 0.3 mm and 0.5 mm, with the 0.5 mm zirconia group showing the highest fracture load among the materials evaluated. However, their study involved primary molars and compared zirconia crowns with zirconia-reinforced lithium silicate and composite resin crowns; therefore, direct comparison with the present study should be made with caution.

Abutment taper also had a significant effect on fracture resistance, with the lower-taper configuration generally demonstrating greater fracture loads than the higher-taper configuration. This may be explained by differences in the geometry and distribution of the restorative material. Increasing the taper alters the internal and external contours of the crown and may influence the direction and concentration of stresses generated during compressive loading. A more conservative taper may provide a more favorable geometric configuration for resisting deformation and crack propagation [13]. Importantly, the effect observed in the present study is supported by an independent investigation demonstrating lower fracture resistance with a substantially greater preparation taper compared to smaller taper configurations. This study also identified the cervical region as a frequent site of fracture initiation, suggesting that preparation geometry may influence stress concentration within monolithic zirconia crowns.

The effect of taper was particularly evident in the thinner crown groups, whereas the difference between the taper configurations was not statistically significant at the greatest crown thickness. This pattern may indicate that increasing restorative thickness provides additional structural reinforcement that partially offsets the mechanical disadvantages associated with greater taper [14]. However, because the thickness-by-taper interaction was not statistically significant, this interpretation should be considered cautiously rather than regarded as evidence of a true modifying interaction. The absence of a significant interaction suggests that the effects of the thickness and taper were largely independent of the conditions examined.

The findings are also consistent with studies demonstrating that factors other than zirconia composition, including preparation geometry, restoration thickness, cementation, die material, and fabrication procedures, can substantially influence measured fracture resistance [13-15]. Jasim et al. [4] reported significant effects of both occlusal thickness and margin design and attributed these differences partly to stress distribution associated with preparation geometry. Similarly, Zimmermann et al. [16] demonstrated that CAD/CAM fabrication and sintering procedures can influence the fracture load of monolithic zirconia crowns of different material thicknesses. These observations emphasize that a direct comparison of absolute fracture-load values between studies should be undertaken cautiously because differences in zirconia composition, crown design, die material, cementation, aging, loading configuration, and fabrication procedures can substantially affect the outcome.

Some findings in the literature appear to differ from the practical implications of the present study. Nakamura et al. [8] reported very high fracture loads, even for 0.5 mm thick monolithic zirconia crowns, and suggested that such restorations could be used in the molar region within the limitations of their experimental model. The apparently greater resistance reported in that investigation may reflect differences in the zirconia material, crown geometry, supporting dies, cementation, and testing conditions rather than a true contradiction. Thus, the present results should not be interpreted as establishing a universal minimum clinically acceptable zirconia thickness.

From a clinical perspective, these findings support a balanced approach between the preservation of tooth structure and mechanical durability. When sufficient restorative space exists, maintaining greater zirconia thickness and avoiding unnecessary excessive abutment taper may provide a greater safety margin against fractures. Conversely, in situations with restricted interocclusal space, reduced-thickness monolithic zirconia may be considered, but careful attention should be given to the preparation geometry and functional loading conditions.

This study has several limitations. First, the in vitro design and use of standardized typodont dies cannot fully reproduce the biological and biomechanical characteristics of natural teeth and the oral environment. Second, fracture resistance was evaluated using a static load-to-failure test rather than cyclic fatigue testing; therefore, the findings cannot directly predict clinical survival. The effects of saliva, periodontal ligament compliance, multidirectional occlusal forces, and prolonged thermomechanical aging were not fully simulated. Furthermore, only three crown thicknesses and two abutment taper configurations were investigated. Future studies incorporating natural teeth, different zirconia generations, cyclic fatigue testing, thermomechanical aging, and clinically representative occlusal conditions are warranted before definitive clinical recommendations regarding minimum crown thickness or optimal preparation taper can be established.

Conclusions

Within the limitations of this in vitro study, monolithic zirconia crown thickness and abutment taper significantly influenced fracture resistance. Greater crown thickness was associated with higher fracture loads, whereas the lower taper configuration generally demonstrated greater fracture resistance. These findings indicate that crown thickness and abutment geometry influence the mechanical performance of monolithic zirconia crowns under the tested conditions. However, the results should not be directly extrapolated to clinical survival, and further studies incorporating cyclic fatigue loading, natural tooth substrates, and clinically representative oral conditions are needed to confirm their clinical relevance.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Arun Jayakumar, Vignesh Guptha Raju

Acquisition, analysis, or interpretation of data: Arun Jayakumar, Selvendran K. Elangovan, Vignesh Guptha Raju

Drafting of the manuscript: Arun Jayakumar, Selvendran K. Elangovan, Vignesh Guptha Raju

Critical review of the manuscript for important intellectual content: Arun Jayakumar, Selvendran K. Elangovan, Vignesh Guptha Raju

Supervision: Arun Jayakumar, Selvendran K. Elangovan

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue.

Animal subjects: All authors have confirmed that this study did not involve animal subjects or tissue.

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

Artificial intelligence (AI) tools, specifically Paperpal (Cactus Communications, Mumbai, India), were used solely for language editing and improving the clarity of the manuscript, and no AI was involved in data generation, analysis, or interpretation.

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