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# Effects of Horizontal Width and Thickness of Zirconia Crown Margin on Fracture Strength

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**Purpose:** The purpose of this study was to evaluate the fracture strength of zirconia crowns of varying margin thicknesses. **Materials and Methods:** A model of the maxillary right first molar (Nissin, Kyoto, Japan) was prepared to create an abutment, which was fabricated into a metal die via a 3D metal printer. CAD software (exocad GmbH, Darmstadt, Germany) was used to design the crowns. A total of eight groups were generated: initially separated by margin thickness (0.1 mm and 0.8 mm), and then further divided by horizontal margin widths of 0.1 mm, 0.2 mm, 0.3 mm, and 0.4 mm. Zirconia crowns were designed for each group's working models (N=10). Crown fracture strength was assessed using a universal testing machine (Shimadzu, Kyoto, Japan), applying a compressive load until fracture and recording the maximum load. A scanning electron microscope was employed to observe fracture patterns. Fracture strength results were analyzed using one-way ANOVA, with the Tukey HSD test applied for post-hoc analysis ($\alpha$=0.05). **Results:** Zirconia crown fracture strength significantly improved with increased horizontal margin width ($P$<0.001). However, margin thickness had no statistically significant effect on fracture strength ($P$=0.513). **Conclusion:** Optimizing the horizontal margin width of zirconia crowns enhances their durability and performance. [J Korean Dent Sci. 2024;17(4):210-20]

**Key Words:** Zirconia crown; Fracture strength; Margin thickness; Crown fracture

## Introduction

Zirconia is an innovative dental prosthodontic material that has recently garnered academic attention[1]. This material exhibits physical properties similar to metal and is one of the strongest dental ceramics[2]. The increasing demand for esthetic restorations has led to the widespread use of zirconia in dentistry, as it offers

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a natural tooth-like color and high durability[3]. The advantages of zirconia include corrosion resistance, biocompatibility, deformation resistance, low thermal conductivity, and excellent wear resistance[4]. Moreover, it demonstrates outstanding resistance to tensile, compressive, and repetitive forces[5].

Despite their widespread use as dental prostheses, zirconia crown fractures remain a major drawback[6]. Zirconia crown fracture resistance is influenced by the shape and amount of tooth reduction during crown preparation[7]. Improperly shaped abutments can destabilize the crown, leading to fractures. Intraoral conditions, such as malocclusion or abutment tooth mobility, can subject the crown to improper forces, increasing fracture risk. Patient habits, including bruxism, hard food consumption, and poor dietary habits, also contribute to the risk of crown fracture[8].

Zirconia crown design significantly impacts fracture resistance. Multiple studies indicate a direct correlation between the crowns' overall strength, shape, features, and thickness[9]. In particular, morphological characteristics and crown margin thickness are crucial in determining fracture strength[10]. These findings serve as a guide for minimizing fracture risks during zirconia crown design and fabrication. Careful consideration of crown shape and thickness enhances crown durability and performance[11].

The role of computer-aided design and computer-aided manufacturing (CAD/CAM) systems in fabricating zirconia crowns is essential in modern dental prosthetics[12]. These systems have significantly reduced reliance on manual labor, enabling high-precision crown fabrication based on digital data[13]. CAD/CAM technology enables precise adjustments in minimum crown thickness, cement space, margin thickness, and margin angle[14]. These adjustments can be tailored to the clinician's experience and patient needs, making CAD/CAM systems invaluable for customized dental solutions[15]. Zirconia crowns produced with these systems offer high accuracy and consistency, establishing them as integral components of patient-specific restorative care[16].

Research on zirconia crowns has explored the effects of margin shape and crown thickness on fracture resistance[17-21]. Although some studies have investigated the effect of margin thickness on the fracture strength of zirconia crowns, research that independently evaluates the influence of margin thickness by distinguishing it into horizontal width and marginal width as separate design factors is limited[22]. The intraoral loading conditions vary among patients, and those with high-risk factors, such as bruxism or excessive occlusal forces, are at greater risk of crown fractures. For such patients, optimizing the margin thickness is crucial to enhancing the durability of crowns and improving the long-term success rate of treatment[23]. Margin thickness plays a significant role beyond physical strength, contributing to the stability and long-term retention of restorations in the oral cavity[24]. Insufficient margin thickness may compromise the fit between the crown and the tooth, leading to crown dislodgement or reduced functionality. In contrast, an optimized margin thickness ensures that occlusal loads are evenly distributed, effectively improving the performance and longevity of the restoration. Additionally, repeated fractures or damage to crowns may increase the cost of remanufacturing and impose a greater treatment burden on the patient.

As margin thickness is directly related to structural integrity, the effect of margin thickness on fracture strength within clinically applicable limits warrants investigation. Such research will optimize zirconia crown design and fabrication, improving clinical performance.

This study aimed to investigate the effects of horizontal margin width and margin thickness of zirconia crowns on fracture strength. It was hypothesized that neither horizontal nor vertical margin thickness would significantly affect the fracture strength of zirconia crowns.

## Materials and Methods

### 1. Specimen Fabrication

The study protocol outlined in Fig. 1 was followed. A metal abutment model was fabricated to evaluate the effect of margin thickness on the fracture strength of zirconia crowns. First, the maxillary right first molar of the study model (Nissin, Kyoto, Japan) was prepared to create an abutment. The tooth was reduced by 2.0 mm occlusally, 1.5 mm axially, and a 1.0 mm chamfer margin width was established. The abutment and adjacent teeth were scanned using a desktop scanner to generate a virtual model, which was then fabricated into a metal abutment using a cobalt-chromium 3D printer. The fabricated metal model was polished and cleaned (Fig. 2).

A single stone model was fabricated from a metal model, scanned using a desktop scanner, and a virtual working model was created. The metal abutment model was used to fabricate one cast with dental impression material and dental stone. A desktop scanner and CAD software (exocad GmbH, Darmstadt, Germany) were then employed to create virtual models of the cast and to design the crowns. The crown designs were divided into two groups based on the increase in vertical margin thickness (0.1 mm and 0.8 mm). Four subgroups were created with horizontal margin width thicknesses of 0.1 mm, 0.2 mm, 0.3 mm, and 0.4 mm (Fig. 3). In total, eight groups were established with 10 working models per group (N=10). The standardized cement space was set at 60 μm for all specimens. In the CAD software used in this study, horizontal width refers to the edge of the crown, while margin width refers to the area transitioning from the horizontal width to the axial wall of the zirconia crown (Fig. 3A). Although these terms are generally collectively referred to as marginal thickness, this study aims to distinguish and define them as horizontal width and margin width, as specified in CAD software.

**Fig. 2.** Experimental metal model.

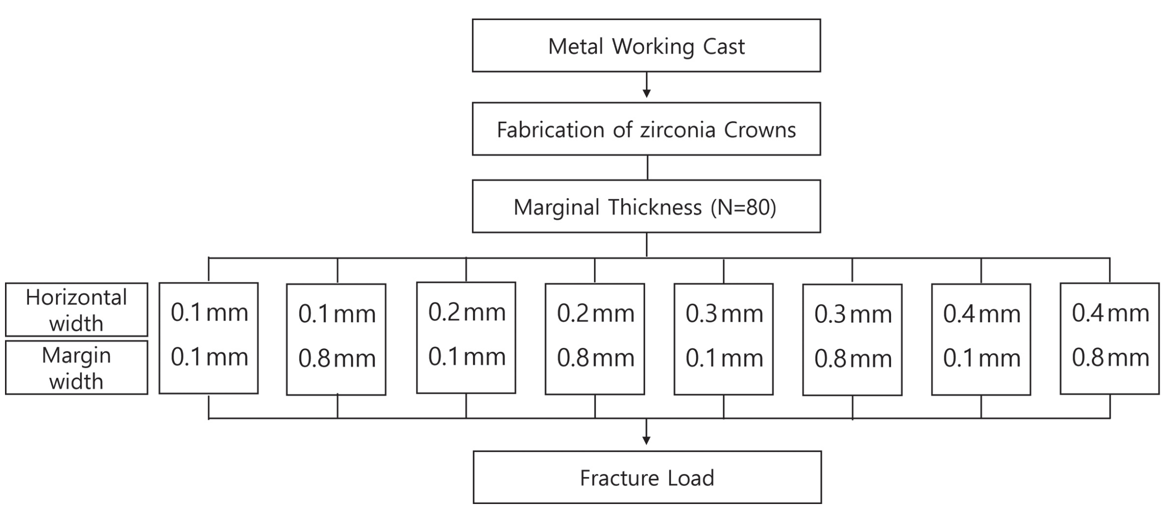


**Fig. 1.** Experimental study flow.

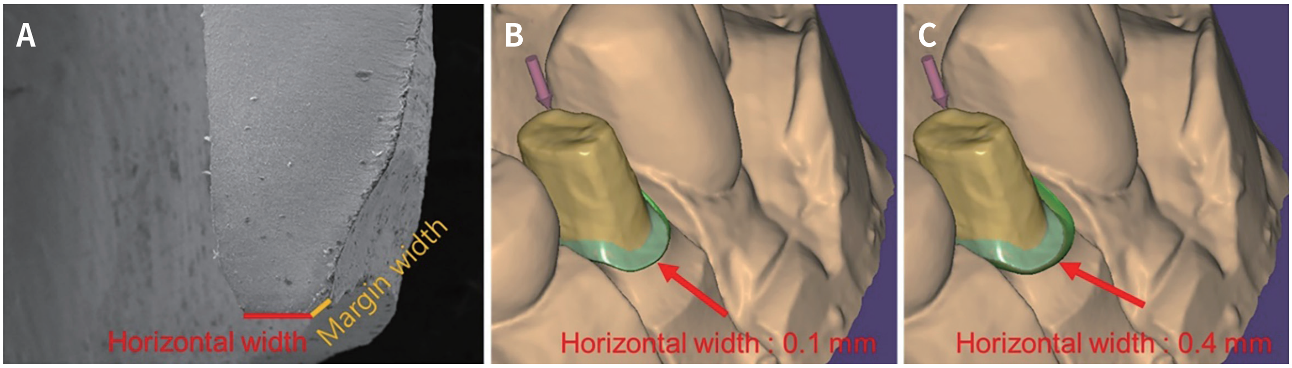


**Fig. 3.** Experimental parameters and crown design. (A) Scanning electron microscope image. (B) Design parameter with a horizontal width of 0.1 mm. (C) Design parameter with a horizontal width of 0.4 mm.

CAM software (HyperDENT, FOLLOW-ME! Technology GmbH, Munich, Germany) and a 5-axis milling machine (250i; Imes Icore, Vatech, Germany) were used to generate the milling paths. A dental zirconia block (Stml Multi Block; Vatech, Seoul, Republic of Korea) and a high-speed rotating diamond cutter were employed to ensure smooth, even milling of the zirconia surface. The crowns were then sintered, with the furnace set according to the manufacturer's recommended temperature and time adjustments.

Prior to the main experiment, a pilot study was conducted to investigate the effects of horizontal width and marginal width on the fracture strength of zirconia crowns. The pilot study included a total of 10 groups, with each group consisting of 5 specimens (N=5). The results showed that an increase in horizontal width led to a statistically significant improvement in fracture strength ($P<0.05$), whereas marginal width did not have a statistically significant effect on fracture strength ($P>0.05$). Consequently, the main experiment was conducted with 10 specimens per group.

### 2. Fracture Strength Evaluation

Crown fracture strength was evaluated using a universal testing machine (Shimadzu, Kyoto, Japan) (Fig. 4). Silicone material (GC Fit Checker; GC Corporation, Tokyo, Japan) was used to secure the zirconia crown to the metal model. A small amount of silicone was applied between the crown and the metal model, followed by the application of appropriate pressure to ensure fixation. The crowns were loaded along the vertical axis at the center of the occlusal surface until fracture occurred. The crosshead speed was set to 1.0 mm/min, and the maximum load at the time of fracture was precisely recorded. Fracture patterns were analyzed using a scanning electron microscope (SEM) (JEOL, Tokyo, Japan) to capture detailed, high-resolution images.

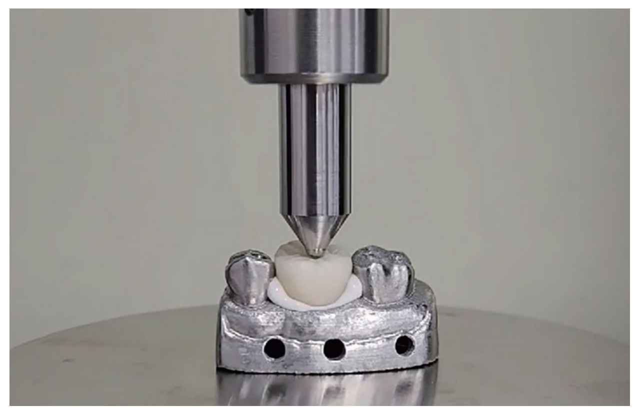

**Fig. 4.** Fracture strength evaluation using a universal testing machine.

### 3. Statistical Analysis

Statistical analysis was conducted using SPSS software (SPSS Inc., Chicago, IL, USA) (α=0.05). The mean and standard deviation of fracture strength values were calculated for each margin thickness group. Differences between groups were analyzed using one-way ANOVA, followed by post-hoc analysis with the Tukey HSD test (α=0.05). Additionally, two-way ANOVA was used to assess the combined effects of horizontal margin width and margin thickness on fracture strength (α=0.05). Partial eta-squared values were calculated to evaluate the impact of each parameter.

## Results

### 1. Fracture Strength Evaluation

The fracture loads of the zirconia crowns were measured to assess the influence of horizontal and margin width parameters (Table 1). Crowns with a horizontal width of 0.1 mm had an average fracture load of 950.0 N (standard deviation (SD)=238.3 N) at a margin width of 0.1 mm (Table 1) (95% confidence interval (CI)=779.5 N - 1120.5 N). The average fracture load increased to 1031.5 N at a margin width of 0.8 mm (SD=149.3 N, CI=924.7 N - 1138.3 N).

The average fracture load at a margin width of 0.1 mm and a horizontal width of 0.2 mm increased to 1100.0 N (SD=191.9 N, CI=962.7 N - 1237.3 N) (Table 1). At a margin width of 0.8 mm, the average fracture load was 1160.0 N (SD=112.7 N, CI=1079.4 N - 1240.6 N). At a horizontal width of 0.3 mm, the average fracture load at a margin width of 0.1 mm was significantly higher at 1283.2 N (SD=64.6 N, CI=1237.0 N - 1329.5 N) (Table 1). The average fracture load with a margin width of 0.8 mm was 1286.0 N (SD=78.0 N, CI=1230.2 N - 1341.8 N).

For crowns with a horizontal width of 0.4 mm and a margin width of 0.1 mm, the highest average fracture load was 1362.4 N (SD=127.5 N, SD=1271.1 N - 1453.6 N) (Table 1). At a margin width of 0.8 mm, the average fracture load decreased slightly to 1305.2 N (SD=141.8 N, CI=1203.7 N - 1406.6 N).

The one-way ANOVA results indicated statistically significant differences in fracture loads across the horizontal width groups (F=9.938, $P$<0.001), confirming that horizontal width had a significant effect on the fracture strength of zirconia crowns (Table 1). Post-hoc Tukey HSD tests revealed significant differences between groups, denoted by letters (A, AB, ABC, BCD, CDF, F). We conducted a two-way ANOVA to evaluate the interaction effects of horizontal and margin width parameters. The impact of horizontal width

**Table 1.** Comparison of zirconia crown fracture loads (N) by horizontal and margin width parameters

| Margin parameter | | Mean | SD | 95% Confidence interval | | Minimum | Maximum | F | *P* | Comparison |
|---|---|---|---|---|---|---|---|---|---|---|
| Horizontal width | Margin width | | | Lower | Upper | | | | | |
| 0.1 | 0.1 | 950.0 | 238.3 | 779.5 | 1120.5 | 467.8 | 1315.9 | 9.938 | <0.001* | A |
| 0.1 | 0.8 | 1031.5 | 149.3 | 924.7 | 1138.3 | 772.4 | 1231.7 | | | AB |
| 0.2 | 0.1 | 1100.0 | 191.9 | 962.7 | 1237.3 | 704.2 | 1392.3 | | | ABC |
| 0.2 | 0.8 | 1160.0 | 112.7 | 1079.4 | 1240.6 | 1024.2 | 1436.1 | | | BCD |
| 0.3 | 0.1 | 1283.2 | 64.6 | 1237.0 | 1329.5 | 1206.8 | 1431.8 | | | CDF |
| 0.3 | 0.8 | 1286.0 | 78.0 | 1230.2 | 1341.8 | 1185.8 | 1397.5 | | | CDF |
| 0.4 | 0.1 | 1362.4 | 127.5 | 1271.1 | 1453.6 | 1063.6 | 1550.5 | | | F |
| 0.4 | 0.8 | 1305.2 | 141.8 | 1203.7 | 1406.6 | 1133.4 | 1593.3 | | | F |

* Significant difference using one-way ANOVA ($P$<0.05). Different letters represent significant differences between groups.

on fracture load was significant ($P<0.001$), with a partial η-squared value of 0.48, indicating a progressive increase in fracture load as horizontal width increased in the sequence of 0.1<0.2<0.3<0.4 (Table 2). However, the effect of margin width on fracture load was insignificant ($P=0.513$), with a partial η-squared value of 0.006. The interaction between horizontal and margin width parameters was also insignificant ($P=0.454$), with a partial η-squared value of 0.036, suggesting that the individual effect of horizontal width was more critical to fracture load than any interaction effect between the two parameters (Table 2).

## 2. Fracture Pattern Evaluation

Fracture patterns were observed and analyzed under a SEM at high magnification (Fig. 5). The typical fracture pattern in all specimens showed cracks initiating at stress concentration areas, radiating outward along the occlusal surface in a stress dispersion pattern. This feature reflects the characteristic uniform fracture behavior of zirconia crowns under an external load.

The fracture patterns varied significantly depending on the horizontal width. In cases with a horizontal width of 0.1 mm, the fractured cross-section was observed near the margin, suggesting that the fracture ini-

**Table 2.** Evaluation of the interaction effects of horizontal and margin width parameters

| Margin parameter | *P* | η-squared | Comparison |
|---|---|---|---|
| Horizontal width | <0.001* | 0.48 | 0.1<0.2<0.3 and 0.4 |
| Margin width | 0.513 | 0.006 | - |
| Horizontal width * Margin width | 0.454 | 0.036 | - |

* Significant difference using two-way ANOVA ($P<0.05$).

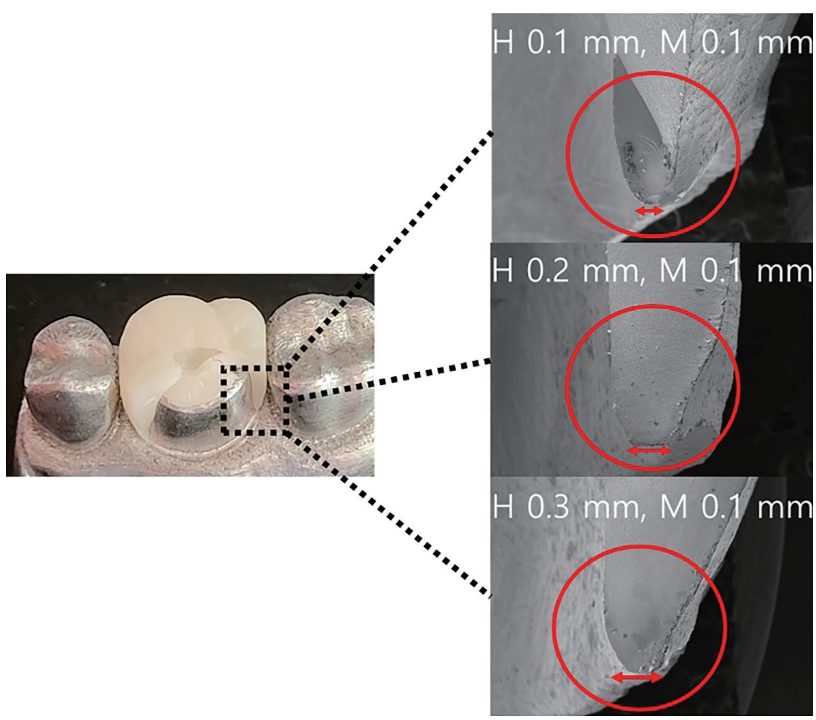


**Fig. 5.** Comparisons of fracture patterns using scanning electron microscope images. H: horizontal width; M: margin width.

tiated at the edge. It is presumed that the concentrated load at the crown margin was the primary cause of the fracture. Stress concentrated at the occlusal edge led to irregular cracks, which rapidly propagated toward the central area of the crown. This indicates that narrower horizontal widths result in external loads being concentrated on specific areas, leading to rapid fracture progression. For a horizontal width of 0.2 mm, the fracture cross-section appeared relatively clean and uniform, demonstrating increased resistance to fracture compared to the 0.1 mm width. Improved stress distribution likely enhanced the structural stability of the crown. In cases with a horizontal width of 0.3 mm, fractures were observed as tears along the inner edge of the crown. This suggests that the resistance to fracture near the crown's edge was further enhanced, providing greater overall resistance. Thus, as the horizontal width increased, stress was more evenly distributed across the occlusal surface, resulting in fractures that were more regular and progressed more gradually. These findings demonstrate that wider horizontal widths facilitate more effective stress distribution, thereby enhancing the structural stability of the crown.

The fracture patterns varied with horizontal width. At a horizontal width of 0.1 mm, stress concentrated at the edges of the occlusal surface, causing irregular cracks that rapidly propagated toward the crown center. This suggests that a narrower horizontal width leads to a higher stress concentration and more rapid fracture propagation. In contrast, stress was distributed more evenly across the occlusal surface with a wider horizontal width of 0.4 mm, resulting in a more regular and gradual fracture progression. A wider horizontal width disperses stress, enhancing the crown's structural stability.

There were minimal differences in fracture patterns based on margin width. Crowns with 0.1 mm and 0.8 mm margin widths exhibited radial cracks originating from the occlusal surface but no significant differences in the fractures' initiation points or propagation rates. This indicates that horizontal width had a more pronounced effect on fracture patterns and stress dispersion than margin width.

SEM analysis showed that a wider horizontal width increases zirconia crown fracture resistance, indicating that horizontal width enhances crown durability and fracture resistance. Moreover, crowns with narrower horizontal widths exhibited more rapid fractures due to stress concentration, highlighting the importance of horizontal width in crown longevity.

## Discussion

This study evaluated the effect of horizontal and marginal width on the fracture strength of zirconia crowns. The results revealed that fracture strength significantly increased with increased horizontal width ($P<0.001$), but did not change significantly based on margin width ($P=0.513$). Thus, we partially rejected our null hypothesis, as horizontal width is critical in influencing the fracture strength of zirconia crowns.

The crown margin and abutment contact areas also increased with increasing horizontal width, leading to stress distribution. This distribution spreads the external load over a larger area, enhancing the crown's structural stability and reducing the fracture risk[23]. These findings align with previous research highlighting improved fracture resistance with increasing crown thickness[24]. This study demonstrates that horizontal width also enhances fracture resistance. Notably, we observed a significant increase in fracture strength as the horizontal width increased to 0.3 mm and 0.4 mm, which has vital clinical implications.

In clinical practice, crowns are exposed to various loads in the oral cavity, and increasing the horizontal width can improve crown stability[25]. This maximizes crown durability and performance, potentially extending the prostheses' lifespan, with reduced maintenance costs and improved patient satisfaction. Moreover, optimizing horizontal width can positively impact periodontal health. Sufficient horizontal width allows the crown margins to better seal against the gingiva, preventing bacterial infiltration and reducing periodontitis risk. Horizontal width is critical in crown design, ensuring long-term prostheses stability[26,27].

However, we found that margin width did not significantly affect fracture strength. Unlike horizontal width, margin width is not subjected to direct occlusal forces and has limited contributions to stress distribution. While a thicker margin width might influence the bond strength at the crown-abutment interface, it does not play a substantial role in load distribution on the occlusal surface. This finding is consistent with previous research indicating that margin design, rather than width, is more closely related to crown fracture resistance[28]. Studies have demonstrated that shoulder margins more effectively disperse occlusal stress, enhancing fracture resistance. However, the present study clarifies that margins do not significantly affect fracture strength[29].

Clinically, these findings suggest that changes in margin width do not substantially contribute to crown durability or strength. Instead, greater emphasis should be placed on optimizing horizontal width, with margin width mainly ensuring proper fit between the crown and abutment. Future research should further analyze how margin design, crown fit, and other factors influence crown longevity and performance[30]. Furthermore, the effect of margin width on the thickness and adequacy of luting agents warrants investigation to determine optimal bonding conditions.

This study highlights the importance of horizontal width in zirconia crown design. Optimizing the horizontal width is essential for extending the crown lifespan and improving patient satisfaction. This helps even the load distribution when the crown is exposed to external forces, particularly high occlusal forces, significantly contributing to long-term fracture prevention. Although we found that margin width had a limited effect on fracture strength, this factor is crucial for a proper abutment-crown fit and enhancing bond strength. Therefore, clinical crown design should consider horizontal and margin widths to ensure optimal crown fit and durability.

Although this study provided valuable insight into the effects of horizontal and margin widths on fracture strength, it has several limitations. First, we conducted this study under fixed laboratory conditions, which do not fully replicate clinical settings. For example, temperature changes, repeated loading, and humidity could affect crown performance. Additional testing, such as thermal cycling or fatigue testing, would better simulate clinical conditions. Thermal cycling tests could help evaluate the effects of temperature fluctuations and humidity on bond strength and fracture resistance. Fatigue testing could assess the long-term durability of crowns under repeated occlusal loads. Second, the study focused solely on fracture strength, although other factors, such as crown fit, wear resistance, and esthetics, are equally important in clinical practice. Future studies should consider these factors to comprehensively evaluate crown performance to provide realistic, reliable clinical guidelines. Wear resistance is particularly crucial, as it determines how long a crown can withstand the wear and tear of daily oral function. Since various factors contribute to wear in the oral environment, assessing wear resistance is vital in evaluating long-term crown performance. Third, Fit Checker (GC Fit Checker; GC Corporation, Tokyo, Japan) was used instead of dental cement to secure the zirconia crown to the metal model. Fit Checker was utilized as a fixation material to maintain the stability of the crown during the experiment and enable repeated measurements. The use of dental cement could have made it difficult to remove and reposition the crown due to adhesive curing, potentially compromising experimental repeatability. Fit Checker provided non-permanent fixation between the crown and the metal model, simplifying the experimental process and overcoming the practical limitation of requiring 90 metal models. However, using Fit Checker as a fixation material instead of dental cement may differ from actual clinical environments. This choice was made to ensure repeatability and control in the experiment.

In future studies, additional research incorporating dental cement will be conducted to supplement the clinical applicability. Fourth, during the experiment, an Instron machine plunger was used to apply a load to the zirconia crown. To directly evaluate the structural response of the crown, no intermediary material was used during load application. The plunger made direct contact with the occlusal surface of the crown to transmit the load. This design was intended to assess the structural characteristics of experimental variables, such as marginal design and crown thickness. However, the absence of intermediary material during load application may not have fully eliminated the possibility of load concentration in specific areas, which is a limitation. Although this design aimed to directly evaluate the structural response of the experimental variables, the potential impact of uneven load distribution on the results must be considered. Future studies will incorporate intermediary materials to equalize load distribution, further enhancing the reliability of the experimental results.

Finally, further research is needed to evaluate the effect of crown design, thickness, and the type and thickness of the luting agent on fracture strength. Such studies would provide a more accurate assessment of crown performance, optimizing their use in various clinical scenarios.

## Conclusion

This study evaluated the effects of horizontal and margin widths on the fracture strength of zirconia crowns. According to the study results, an increase in horizontal width significantly improved the fracture strength of the crowns, demonstrating that optimizing horizontal width is a critical design variable for enhancing structural stability and durability in crown design. In contrast, margin width did not have a statistically significant effect on fracture strength. This suggests that the individual effect of horizontal width plays a more substantial role in load distribution and durability during crown design. This finding suggests that horizontal width is a critical factor in the structural stability of zirconia crowns. However, changes in margin width did not significantly impact fracture strength. Therefore, optimizing horizontal width improves the durability and performance of zirconia crown design.

According to the study results, an increase in horizontal width significantly improved the fracture strength of the crowns, demonstrating that optimizing horizontal width is a critical design variable for enhancing structural stability and durability in crown design[31]. In contrast, margin width did not have a statistically significant effect on fracture strength. This suggests that the individual effect of horizontal width plays a more substantial role in load distribution and durability during crown design.

These findings clarify the optimal zirconia crown design and manufacturing techniques to enhance clinical performance. Future studies should include additional experiments, such as thermocycling tests and fatigue tests, to simulate actual intraoral conditions and address the limitations of this study. Furthermore, a comprehensive analysis of the effects of marginal thickness on various factors, including crown fit, aesthetics, and wear resistance, will enable the development of more practical and comprehensive clinical design guidelines.

In conclusion, optimizing zirconia crowns' horizontal width can improve fracture strength, maximizing its longevity and clinical performance. This research may be an important reference for future prosthodontic design and fabrication practices.

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