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다양한 부위에서의 감소된 두께가 지르코니아 크라운의 파절 저항에 미치는 영향

The effect of reduced thickness in different regions on the fracture resistance of monolithic zirconia crowns

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Purpose. This study aims to evaluate the combined effect of reduced thickness in different regions on the fracture resistance of monolithic zirconia crowns. **Materials and methods.** Seven nickel-chromium dies were generated from a 3D model of mandibular first molar using the digital scanner with the following geometries: 1.5 mm occlusal reduction, 1.0 mm deep chamfer. Based on the abutment model, Zirconia blocks (Luxen Zirconia) were selected to fabricate Sixty-three zirconia crowns with occlusal thicknesses of 0.3 mm, 0.5 mm, and 1.5 mm, and different axial thicknesses of 0.3 mm, 0.5 mm, and 1.0 mm. All crowns were cemented by resin cement. Next, the crowns were subjected to load-to-fracture test until fracture using an electronic universal testing machine. In addition, fracture patterns were observed with a scanning electron microscope (SEM). Two-way ANOVA and the Tuckey HSD test for post hoc analysis were used for statistical analysis (P < .05). **Results.** The mean values of fracture resistancerecorded was higher than the average biting force in the posterior region. The two-way ANOVA showed that the occlusal and axial thickness affected the fracture resistance significantly (P < .05). However, the effect of axial thickness on fracture resistance did not show a statistical difference when thicker than 0.5 mm. The observed failure modes were partial or complete fracture depending on the severity of crack propagation. **Conclusion.** Within the limitations of the present study, the CAD-CAM monolithic zirconia crown with extremely reduced thickness showed adequate fracture resistance to withstand occlusal load in molar regions. In addition, both occlusal and axial thickness affected the fracture resistance of the zirconia crown and showed different results as combined. (J Korean Acad Prosthodont 2022;60:135-42)

Keywords
Fracture resistance; *In vitro*; Occlusal/Axial thickness; Zirconia crown

Introduction

The abutment preparation protocol for monolithic yttrium stabilized zirconia crown requires a certain amount of restoration thickness[1] to withstand the human bite force.[2-5] However, this could lead to a significant reduction of tooth structure from both mechanical and biological perspectives. According to Edelhoff, preparation for a full veneer crown might reduce up to 30% of total tooth volume.[6] Furthermore, the fracture strength of a compromised abutment decreases invariably according to the size and position of the defects.[7,8] Moreover, it has been reported that an abutment may lose vitality after the preparation procedure.[9,10] Kontakiotis *et al*.[11] investigated the incidence of pulp necrosis after tooth preparation. 9 out of 120 examined teeth lost their tooth vitality after preparation which all had healthy pulp before the treatment. 9% of pulp necrosis and subsequent endodontic treatment might be called the biologic price of prosthodontic intervention.[12] Therefore, it would be desirable to reduce the restoration thickness to a point where sufficient strength can be maintained.

The strength of zirconia restorations depending on the material thickness was tested. Sorrentino *et al*.[13] compared the fracture strength of zirconia crowns with different occlusal thicknesses of 0.5, 1.0, 1.5, and 2.0 mm. The specimens were cemented on human teeth and were loaded until fracture. The result showed a tendency of decreasing fracture strength by reducing the thickness. However, the difference was not significant, and it was suggested that the fracture load of a zirconia crown was not affected by the occlusal thickness. Since the fracture load of tested crowns exceeded both the physiologic and parafunctional occlusal load in the molar area, the authors concluded that the occlusal thickness of 0.5 mm would be sufficient to withstand the occlusal load in the molar region. However, it should be noted that in this study, the axial wall thickness was maintained at 1 mm.

The strength of the zirconia restoration regarding the axial thickness was studied. Øilo *et al*.[14] compared the fracture strength of 0.4 mm and 0.8 mm, axial thickness groups, with the same occlusal thickness of 1 mm. They concluded that the thicker axial group had significantly higher fracture strength. Similarly, Skjold *et al*.[15] reported that the presence of a cervical collar would increase the fracture strength of the zirconia restoration. These studies might indicate a specific effect of axial thickness on the strength of the zirconia crown. However, Nakamura *et al*.[16] reported that axial wall thickness had no significant impact on the strength of the zirconia crown. The fracture load experiment with different occlusal and axial thicknesses showed that the strength was dependent on the occlusal thickness factor.

A literature review has shown that the strength of the zirconia crown could vary according to different thicknesses and geometry. Therefore, the purpose of this study was to validate the combined effect of reduced thickness of different regions on the fracture strength of monolithic zirconia crowns. The alternative hypothesis was that there was significant difference in the zirconia crown's fracture load according to the tested parameters.

Materials and methods

Abutment die fabrication

The first mandibular molar tooth of the dental model (Nissin Dental products Inc., Kyoto, Japan) was scanned using a digital scanner (E3 Scanner; 3Shape, Copenhagen K, DK). With the scanned image, abutments were designed with the following geometries: 1.5 mm occlusal reduction, 1.0 mm depth peripheral circumferential deep chamfer margin placed 0.5 mm above the cementoenamel junction, and 12° of total occlusal convergence. In addition, all the line angles were rounded (Fig. 1A), and the base design was incorporated into the abutment for the experiment. The data of digital abutment teeth were imported into milling machine (Arum 5x-300; Hoil Dental, England, UK), and seven abutment models were milled from Ni-Cr alloy block (Freemill Nice; Yuseung Co., Ltd., Gyeongsangnam, Korea) (Fig. 1B).

Zirconia crown fabrication

Based on the abutment model, the first group of zirconia crowns with a different occlusal thickness of 0.3, 0.5, and 1.5 mm were designed. The axial wall thickness was provided as 0.3 mm in common. As such, the identical set of zirconia crowns were designed with axial wall thicknesses of 0.5 mm and 1.0 mm. A 70 µm thick cement layer was provided on all groups according to the default setting of the CAD-CAM software (Dental System; 3Shape, Copenhagen K, DK). Seven zirconia crowns were milled from zirconia block (Luxen Zirconia; Dentalmax, Seoul, Korea) for each occlusal and axial wall thickness group (Fig. 1C) which were sintered (Luxen furnace; Dentalmax, Seoul, Korea) under the manufacturer's guidelines and thus, 63 crowns in total (Table 1).

Cementation procedure

Each crown was cemented to the die with resin cement (Rely X™ U200; 3M/ESPE, Seefeld, Germany). according to the manufacturer's instructions (Fig. 1D). Intense finger pressure was applied to the occlusal surface of each crown. Excess cement was removed immediately after loading. Prior to mechanical testing, the crown-die samples were kept at 37°C for 24 h before fracture test for hardening.

Fracture test with universal testing machine

The test specimens were placed on the universal testing machine (Model 8871; Instron, Norwood, MA, USA). A stainless-steel custom-made, 5 mm diameter hemisphere indenter was secured on the load cell. A thin polyethylene sheet with a thickness of 0.04 mm was placed between the indenter and occlusal surface for better force distribution (Fig. 1E, F). The load-to-fracture test was applied via the indenter in the central fossa of the occlusal surface. The load was applied in a direction parallel to the longitudinal axis of the crown-die specimen at a

Table 1. Experimental design

Occlusal thickness (mm)	Axial thickness (mm)	Number of specimens
0.3	0.3	7
	0.5	7
	1.0	7
0.5	0.3	7
	0.5	7
	1.0	7
1.5	0.3	7
	0.5	7
	1.0	7

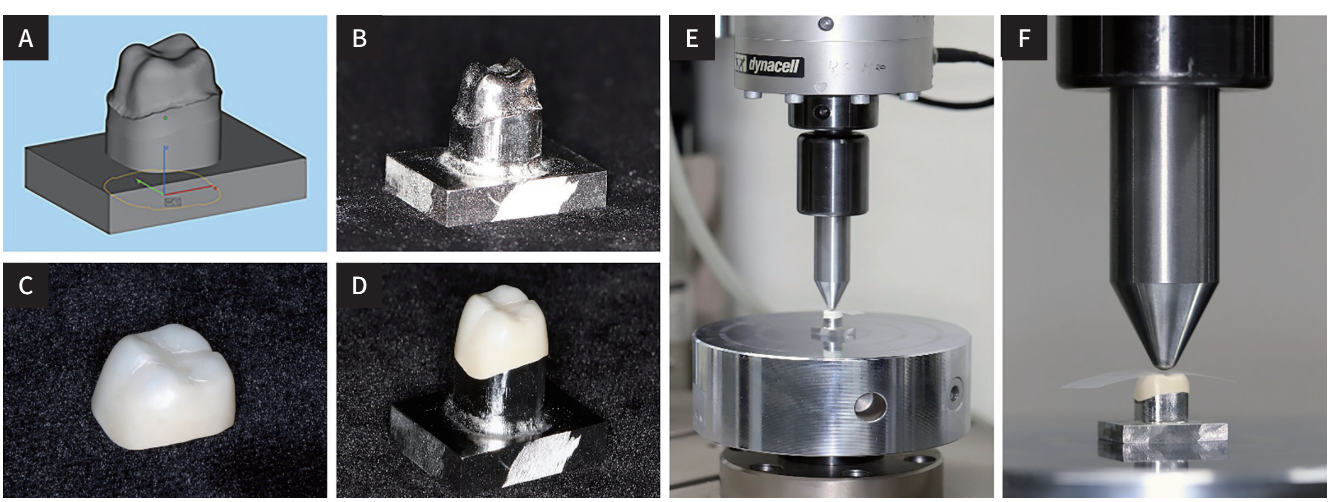

Fig. 1. The abutment design and crown fabrication (A - D). (A) The abutment design, (B) Abutment die of Ni-Cr alloy, (C) Zirconia crown, (D) The zirconia crown cemented on the abutment. (E - F) Fracture load test with the universal testing machine and the experimental setup.

cross-head speed of 0.5 mm/min until fracture occurred. The failure load curve that appeared on the control display part of the universal testing machine was carefully monitored during the test. The test was stopped at the first sign of failure, characterized by a sudden dip in the applied load. In addition, the representative samples were chosen and subjected to a scanning electronic microscope (JSM-7800F; JEOL Ltd., Tokyo, Japan) to observe the crack propagation initiation site and failure mode.

Statistical analysis

The fracture load values were statistically analyzed using two-way ANOVA analysis of variance. The level of significance was set at ($P < .05$). Post-hoc Tuckey test was planned for multiple comparisons to determine the significance of difference among the variable groups if existed.

Results

The fracture load of zirconia crowns with different occlusal and axial thickness are shown in Table 2. Overall, the fracture load increased as the occlusal and axial thickness of the crown increased (Fig. 2). However, the 0.5 mm occlusal thickness group showed there was a decrease in fracture load as the axial thickness increased from 0.5 mm to 1.0 mm (Fig. 3).

Two-way ANOVA results showed there was significant difference within the occlusal thickness groups as well as within the axial thickness groups. And there was significant difference in between both variable groups. Therefore, the null hypothesis was rejected. The data favored the alternative hypothesis that significant difference in fracture load of zirconia crowns existed among different occlusal and axial thickness.

The post-hoc Tuckey test showed the differences in detail within each group. Regarding the occlusal thickness group, all of the groups showed significant difference

Table 2. The mean fracture load and standard deviation of tested zirconia crown groups

Occlusal thickness (mm)	Axial thickness (mm)	Mean fracture load (N)	Standard deviation
0.3	0.3	1267.48	64.83
	0.5	1722.25	304.09
	1.0	2668.26	860.33
0.5	0.3	2691.31	545.08
	0.5	4838.55	387.37
	1.0	2803.50	517.31
1.5	0.3	4566.63	575.94
	0.5	5212.89	550.94
	1.0	5742.68	1049.92

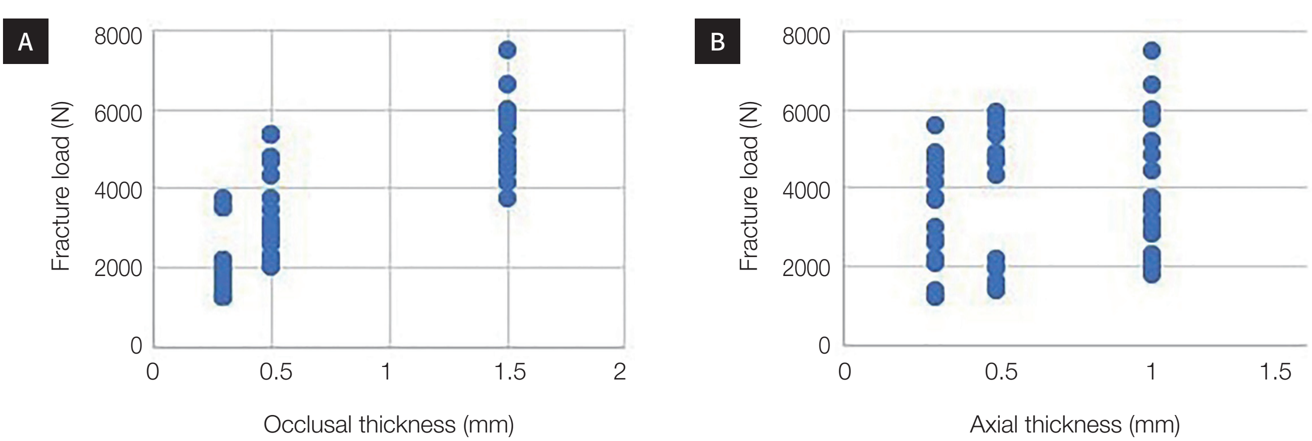

Fig. 2. The distribution of the fracture load according to (A) occlusal thickness and (B) axial thickness.

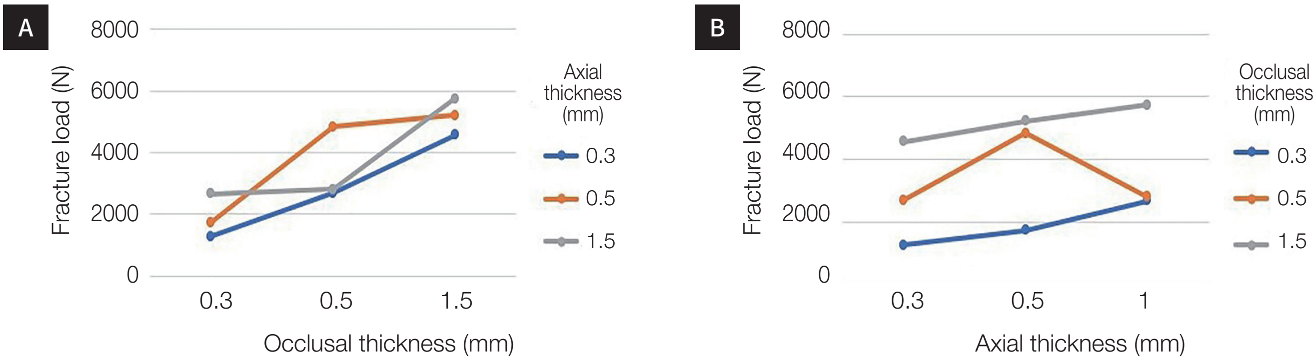

Fig. 3. The mean fracture load of each groups plotted according to (A) X axis as occlusal thickness and (B) X axis as axial thickness.

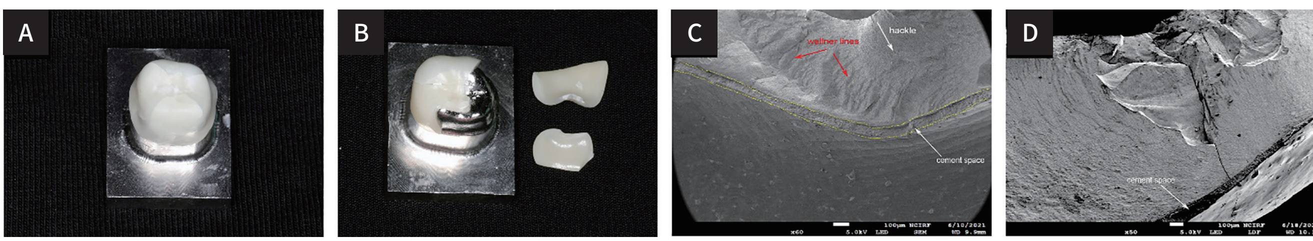

Fig. 4. Failure mode of fractured specimens (A - B), SEM views of fractured zirconia crowns (C - D). (A) cracks with partial fracture and (B) complete fracture, (C) The Wallner lines (red arrows) showed the crack initiated from the center of the occlusal surface. Hackle on the occlusal surface confirmed crack propagation direction marked by the white arrow (×60), (D) The crack penetrated the crown until it reached the cement space (×50).

from each other. Regarding the axial thickness group, most of the groups showed significant difference from each other except between 0.5 mm group and 1.0 group.

Two types of fracture mode (Fig. 4A, B); partial and complete fracture were observed irrespective of crown thickness. Complete fractures were observed more frequently. The loading indenter was in contact with the slopes of the cusps. Cracks initiated from the occlusal surface below the tip of the indenter, penetrated the crown and eventually extended to the periphery of the specimens. Images of fractured samples from scanning electron microscope showed the crack initiation site and direction of the crack propagation (Fig. 4C, D).

Discussion

All fracture load values in this study were above what was considered as maximum bite force; 900 N.[2,3] However, the mean fracture load of the thinnest group, 1267.48 N, did not reach the clenching force reported in bruxers.[4,5] Therefore, based on the results, extremely thin 0.3 mm thickness could not be provided simultaneously as the occlusal and axial thickness of the restoration. Either occlusal or axial thickness had to be greater than 0.3 mm to provide sufficient resistance.

The result was analyzed according to two different categories: occlusal and axial wall thickness (Fig. 2, Fig. 3). The occlusal thickness was a significant factor in de-

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termining the fracture resistance of the restoration. All three occlusal thickness groups that were tested showed significantly different fracture load from each other. The thicker the occlusal thickness of the restoration, the stronger it was. It was also noted that axial thickness played a certain role in determining the fracture resistance of the restoration. Based on the results, as long as the axial thickness remained thicker than 0.5 mm, the fracture resistance of the zirconia crown groups was not significantly different from each other regardless of the occlusal thickness. This result was in accordance with the previous study from Sorrentino *et al*.[13] However, when the axial thickness was reduced to 0.3 mm, the difference in occlusal thickness affected the fracture resistance significantly.

In the present study, 3% mol of yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) has been used for superior mechanical properties due to an inherent transformation toughening mechanism which resists crack generation and enhances crack propagation resistance. The observed failure modes of zirconia crowns were fracture associated with crack irrespective of crowns thickness. The direction of hackles suggested that the cracks initiated from the occlusal surface then spread towards the axial surface. Thus, the occlusal surface was the first place to resist fracture. However, as the fracture resistance of the crown was not statistically different when the axial thickness was greater than 0.5 mm, it would be reasonable to regard the axial thickness as a secondary factor to resist fracture. It could be suggested that the axial wall might have an assisting or reinforcing role to withstand the tensile stress developing in the occlusal surface area. As the axial wall thickness was less than 0.5 mm, the crown's resistance depended on the occlusal thickness factor.

There have been several studies[16-19] regarding the resistance of the zirconia crown according to thickness. A common aspect of these studies is that each specimen had a uniform thickness. Unlike previous studies, this study provided different thicknesses in a single specimen and evaluated these factors separately as well as in combination. It was noted that with extremely reduced thickness, the resistance could be affected not only by a single factor but also by the overall geometry of the crown.

The present study has limitations. The load to fracture test was performed without dynamic loading or aging procedures. From a mechanical viewpoint that a 20 - 40% reduction in fracture load might occur as a result of cyclic loading in an aqueous environment,[20,21] the experimental setup of this study might not be sufficient to simulate the oral environmental effects. The purpose of this study was to validate the combined effect of various geometry of the crown on the fracture resistance of the zirconia crown. Therefore, other factors were not included in the study in order to simplify the variables. The use of natural teeth mimics clinical conditions more closely than metal abutments. However, it leads to a high diversity of fracture results and limits its importance. Therefore, standardized metal dies are used to maximize reproducibility and comparability with existing studies. Another limitation was that the factors in this study might be an oversimplified scheme considering the complexity of a crown morphology. Therefore, technically detailed further studies regarding the fracture behavior of a zirconia crown shall be required.

Conclusion

Within the limitations of this *in vitro* study, the CAD-CAM monolithic zirconia crown with extremely reduced thickness showed sufficient fracture resistance. Both occlusal and axial thickness contributed to the fracture resistance of the zirconia crown. However, when the axial thickness was above 0.5 mm, the effect of the axial thickness on the fracture resistance of the zirconia crown did not show the difference.

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다양한 부위에서의 감소된 두께가 지르코니아 크라운의 파절 저항에 미치는 영향

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목적: 이번 연구의 목적은 단일구조 지르코니아(monolithic zirconia) 크라운의 서로 다른 부위에서, 감소된 지르코니아의 두께가 파절 저항성에 미치는 복합적인 영향을 평가하기 위한 것이다. **재료 및 방법:** 실험을 위해 7개의 니켈-크롬 다이를 제작하였다. 다이는 하악 제 1대구치를 치아 형성한 지대치 3D 모델을 바탕으로 제작되었다. 지대치는 1.5 mm 교합면 삭제를 시행하였고, 변연은 1.0 mm의 deep chamfer로 형성하였다. 이 지대치 형태를 바탕으로 지르코니아 블록(Luxen Zirconia)를 사용하여, 교합면 두께는 0.3 mm, 0.5 mm, 1.5 mm, 축면 두께는 0.3 mm, 0.5 mm, 1.0 mm로 설정한 63개의 지르코니아 크라운을 제작하였다. 이 크라운은 니켈 크롬 다이에 레진 시멘트를 이용하여 접착하였다. 그 다음, electronic universal testing machine을 사용하여 크라운이 파절될 때까지 load-to fracture 시험을 진행하였다. 이후 scanning electron microscope (SEM)를 사용하여 크라운의 파절 형태를 관찰하였다. 통계 분석을 위해 Two-way ANOVA 방법을 사용하였고, 이에 대하여 Tuckey HSD test로 사후 검정을 시행하였다(P < .05). **결과:** 모든 지르코니아 크라운의 평균 파절 저항 값은 구치부의 평균 저작력보다 큰 값을 나타냈다. 또한 Two-way ANOVA 결과, 지르코니아 크라운의 교합면 두께와 축면 두께는 파절 저항에 통계적으로 유의한 영향을 미치는 것으로 나타났다(P < .05). 그러나, 지르코니아의 축면 두께가 0.5 mm 이상일 때, 파절 저항에 미치는 영향은 통계적으로 유의한 차이를 보이지 않았다. 나타난 파괴 양상은 균열의 전파 양상에 따라 크라운의 부분 파절 또는 완전 파절로 나타났다. **결론:** 이번 연구의 한계 내에서, 극도로 감소된 두께를 가진 CAD-CAM 단일구조 지르코니아 크라운은 구치부 교합력을 견딜 수 있는 적절한 파절 저항을 보였다. 또한, 지르코니아 크라운의 교합면 두께와 축면 두께는 파절 저항에 유의미한 영향을 나타냈으며 복합적인 결과를 보였다. (대한치과보철학회지 2022;60:135-42)

주요단어

파절 저항료; 생체 외 실험; 교합면 두께; 축면 두께; 지르코니아 크라운

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