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Effect of Reduced Occlusal Thickness with Two Margin Designs on Fracture Resistance of Monolithic Zirconia Crowns

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Abstract

Objectives The aim of this study was to compare the effects of two margin designs (shoulderless and slight chamfer) with two occlusal thicknesses on fracture resistance and failure mode of the monolithic zirconia crowns.

Materials and Methods Forty nickel–chromium dies were duplicated from the previous two prepared teeth using a three-dimensional optical scanner. Nickel–chromium supporting dies were divided into two main groups (n = 20) according to the type of margin design: group A, slight chamfer margin design and group B, shoulderless margin design. These groups were further divided into two subgroups according to the occlusal thicknesses (0.5 and 1 mm). The digital imaging of each die was done using a three-dimensional optical scanner, then zirconia blocks were milled by 5-axis machine. The crowns were cleaned by alcohol, air dried, and cemented by resin cement. Next, the crowns were subjected to 500 hot and cold cycles (30 seconds for each cycle). The samples were subjected to a static load until failure using an electronic universal testing machine and fracture resistance was recorded in Newton (N).

Statistical Analysis Data were analyzed using the test of normality (Shapiro–Wilk test) and two-way analysis of variance (ANOVA) test.

Results The highest mean fracture load was recorded by the shoulderless (1 mm occlusal thickness) subgroup (3,992.5 N), followed by shoulderless (0.5 mm occlusal thickness) subgroup (3,244.4 N), and the slight chamfer (1 mm occlusal thickness) subgroup (2,811 N). The lowest mean of fracture load was recorded by slight chamfer (0.5 mm occlusal thickness) subgroup (1,632.9 N). The two-way ANOVA test revealed a significant difference between the four subgroups. Regarding the fracture mode, the slight chamfer subgroups showed a severe fracture of the restoration while the shoulderless subgroups showed a fracture through the midline of the restoration.

Conclusion Within the limitation of the comparative study, shoulderless margin design has a more favorable outcome than a slight chamfer design in all thicknesses. Although the restoration with reduced occlusal thickness has lower fracture resistance than 1 mm occlusal thickness, the 0.5 mm restorations still can tolerate occlusal forces.

Keywords
- ► zirconia
- ► shoulderless
- ► chamfer
- ► occlusal thickness

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Introduction

Zirconia has been used extensively in the last decades due to higher mechanical properties.[1] The veneering layer was used to enhance the esthetic of restoration due to the opaque color of the zirconia core.[2,3] But this, in turn, may result in failure (adhesive or cohesive) of the veneering layer.[4] The monolithic zirconia restorations can be used successfully in many clinical situations by omitting the veneering porcelain layer.[5]

The recommendation of the margin design for high-strength ceramic materials, such as zirconia, is not evident, as the clinical recommendations are still based on that for all-ceramic and metal-ceramic crowns.[6] The monolithic zirconia restorations can be used successfully in clinical situations especially in patients with limited interocclusal distance and in patients with high occlusal loads.[7,8] Thus, it is possible to reduce the invasive preparation of teeth by the use of monolithic high-strength ceramics.[9,10]

The fracture resistance of monolithic zirconia crown restorations with reduced occlusal thickness may show higher successful clinical results than other ceramic materials due to high-flexural strength (>1,000 MPa).[8]

There are few data available about the fracture resistance of monolithic restorations with shoulderless margin designs and different occlusal thicknesses. Thus, the aim of this study was to compare the effects of two margin designs (shoulderless and slight chamfer) with two occlusal thicknesses on fracture resistance and failure mode of the monolithic zirconia crowns.

Materials and Methods

Two sound human maxillary first premolar teeth extracted for orthodontic needs were selected with comparable size and shape as measured with a digital caliper (POWER FIX Profi; Owim, Neckarsulm, Germany).

To maintain standardization during preparation of samples, surveyor for dental use (Paraline; Dentaurum, Ispringen, Germany) with a modification to grasp a turbine hand-piece (DynaLED M600LGM4; NSK, Tokyo, Japan) was used for this purpose, thus the bur that was used to prepare the axial walls of the tooth sample became parallel with the long axis of it, this step was checked and confirmed by the use of a protractor to ensure the total convergence angle of the prepared tooth. Both prepared teeth have a 5 mm occlusocervical height with planar occlusal reduction and this was done by using barreled-shaped bur (811 314 037; Komet, Siege, Germany) and a line was drawn 1 mm above the cemento-enamel junction (CEJ) with a marker (Staedtler; Nuremberg, Germany) and this represents the margin design. A specific criteria for each prepared tooth, one tooth was prepared for a slight chamfer margin design of 0.5 mm width with guide-pin round-end tapered fissure bur (6856P 314 018; Komet, Siege, Germany) and finishing step was done by using round-end tapered fissure bur (8856 314 016; Komet, Siege, Germany) and a total convergence of 6 degrees, the other tooth was prepared for a shoulderless margin design with a flame shape tapered fissure bur (6862 314 012, Komet, Siege, Germany) and finishing step was done by using this type of bur (8862 314 010; Komet, Siege, Germany) and a total convergence of 4 degrees. Then 40 nickel–chromium dies (realloy-N+, 190124, really e.k, Krefeld, Germany) were duplicated from the previous two prepared teeth by using a three-dimensional optical scanner (Deluxe; Open Technologies, Rizzato BS, Italy) and then milled by using 5-axis milling machine (D15; Yenadent, İstanbul, Turkey).

Nickel–chromium supporting dies were divided into two main groups ($n = 20$) according to the type of margin design: group A, slight chamfer margin design and group B, shoulderless margin design. These groups were further divided into two subgroups according to the minimum occlusal thicknesses; a minimum 1 mm occlusal thickness for subgroup A1 and B1, while a minimum 0.5 mm occlusal thickness for subgroup A2 and B2.

Digital image to each die was done by using a three-dimensional optical scanner (Deluxe) and milled by using a five-axis milling machine (D15) with 80-μm spacer and a minimum occlusal thickness of 1 mm for subgroups A1 and B1 and 0.5 mm for subgroups A2 and B2 and the material used was zirconia blocks (IPS e.max ZirCAD MT A2 98.514 mm; Ivoclar digital, Liechtenstein, Germany) to make the crowns. Then the sintering of zirconia crowns was done by the use of sintering furnace (HT-S speed; Mihm-Vogt, Stutensee-Blankenloch, Germany).

Crowns were glazed (Vita Akzent Plus Glaze LT; VITA Zahnfabrik, Bad Säckingen, Germany) and then furnaced (Vita Vacumat 40 T; VITA Zahnfabrik, Bad Säckingen, Germany) at 910°C.

Cleaning of monolithic zirconia crowns was done in 96% ethanol alcohol for 5 minutes by the use of ultrasonic cleaner (Digital Heated Ultrasonic Cleaner; H&B Luxuries, Zhuhai, Guangdong, China) and then air-dried.

In this study, the cementation of each crown on its respective die was done by the use of self-adhesive resin cement (Rely X U200; 3M ESPE, Neuss, Germany). At first, the intaglio surface of zirconia restoration was coated with two coats of zirconia primer (Z-PRIME plus; Bisco, IL, United States) and air dried for 3 to 5 seconds according to the manufacturer recommendations. Then, the intaglio surface of zirconia was covered with injected resin cement by the use of a mixing tip to produce an even thin layer of cement material. The zirconia crown placed over its respective dies was secured with a screw that was attached to a load sensor to maintain the seating force of 50 N by using a custom made holding device and a rubber material placed on the occlusal surface of the crown to avoid direct contact damage and to imitate the clinical situation. Then water storage for 1 week at 37°C.

Thermocycling to all specimens was done using a specially fabricated machine, the specimens were subjected to temperature (5 and 55°C) for 500 cycles (every cycle consists of 30 seconds).

The fracture test was done by using a universal testing machine (universal testing machine; Laryee Technology, Beijing, China), the applied test was done by using a single static load. The load was applied in a vertical manner on the occlusal surface at the central fossa of crowns at 0.5 mm/min cross-head speed and 4 mm diameter with a round-end indenter made from stainless steel. All zirconia crowns were loaded until failure and the readings were automatically registered in Newton.

Table 1 The codes used to demonstrate the fracture mode[10]

Code	Description
I	"Minimal fracture or crack in a crown"
II	"Less than half of a crown lost"
III	"Crown fracture through a midline" "(half of the crown displaced or lost)"
IV	"More than half of a crown lost"
V	"Severe fracture of a tooth and/or a crown"

The fracture mode was performed as stated by burke in 1999 as shown in ►**Table 1**,[11] and the tested specimens were assessed by the use of a digital microscope (Koolertron; Shenzhen, China) at ×10 magnification.

Statistical analyses of the results were done using the SPSS program (SPSS Statistics for Windows, version 25.0; IBM Corp., Armonk, NY, United States). The normal distributions of the results were evaluated by the use of Shapiro–Wilk test.

Results

The normal distributions of the results were established by the use of Shapiro–Wilk test. Therefore, descriptive statistics (means and ±standard deviation [SD]) were recorded as shown in ►**Table 2**. The statistical analysis was done by the use of two-way analysis of variance (ANOVA) test to calculate the influence of the two variables, a significant difference for both margin design and occlusal thickness but no significant interaction difference between them as shown in ►**Table 3**.

The highest mean fracture resistance value of monolithic crowns was recorded by shoulderless (1 mm occlusal thickness) subgroup (3,992.5 ± 627.82 N) and the lowest mean fracture value was recorded by slight chamfer (0.5 mm occlusal thickness) subgroup (1,632.9 ± 247.51 N).

Reducing the occlusal thickness of the restoration from 1 to 0.5 mm accompanied by 42% reduction of resistance to fracture in the slight chamfer subgroups and 19% in the shoulderless subgroups. The change in preparation design (from shoulderless to slight chamfer) with similar occlusal thicknesses resulted in 50% reduction of resistance to fracture of 0.5 mm groups and 30% in 1 mm subgroups.

Concerning the fracture mode, results showed that the major number of samples from subgroups A1 and A2 showed a severe fracture of the crown (code V), while a midline fracture (fracture through the central fossa; code III) occurred in samples from subgroups B1 and B2. Code-I fracture was not observed in either subgroups (►**Fig. 1**; ►**Table 4**).

Table 2 Data for the failure load (means and ±SD) in Newton

	Subgroup A1	Subgroup A2	Subgroup B1	Subgroup B2
Margin design	Chamfer	Chamfer	Shoulderless	Shoulderless
Occlusal thickness (mm)	1	0.5	1	0.5
Mean and ±SD	2,811 (364.51)	1,632.9 (247.51)	3,992.5 (627.82)	3,244.4 (401.01)

Abbreviation: SD, standard deviation.

Table 3 Two-way ANOVA test for both margin design and occlusal thickness and the interaction difference between them

Tests of between-subjects effects					
Dependent variable	**Fracture resistance of monolithic zirconia crowns**				
Source	Type-III sum of squares	df	Mean square	F	Sig.
Margin design	19,502,122.500	1	19,502,122.500	104.135	0.000
Occlusal thickness	9,275,616.100	1	9,275,616.100	49.52	0.000
Margin design vs. occlusal thickness	462,250.000	1	462,250.000	2.46	0.125

Abbreviation: ANOVA, analysis of variance; Sig., significance.

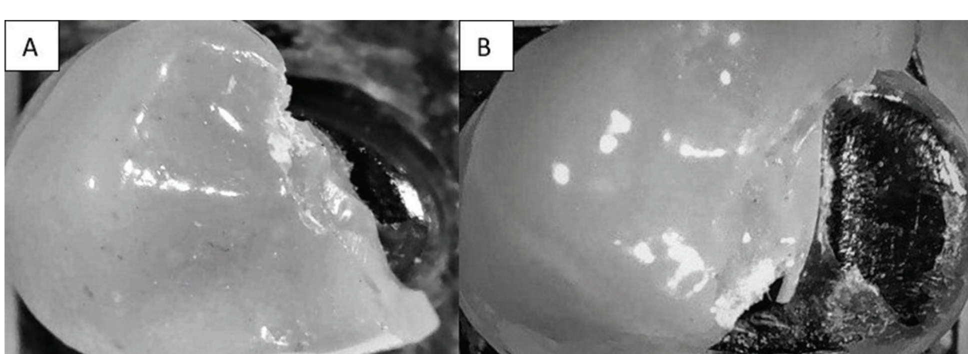

Fig. 1 Images were taken under a digital stereomicroscope at ×10 to assess the fracture mode: (**A**) severe crown fracture for chamfer subgroups, (**B**) crown fracture through the midline for shoulderless subgroups.

Table 4 The fracture mode

Subgroups	Code I (%)	Code II (%)	Code III (%)	Code IV (%)	Code V (%)	Total
A1	–	–	–	2 (20)	8 (80)	10 (100)
A2	–	2 (20)	–	2 (20)	6 (60)	10 (100)
B1	–	–	7 (70)	–	3 (30)	10 (100)
B2	–	–	8 (80)	–	2 (20)	10 (100)

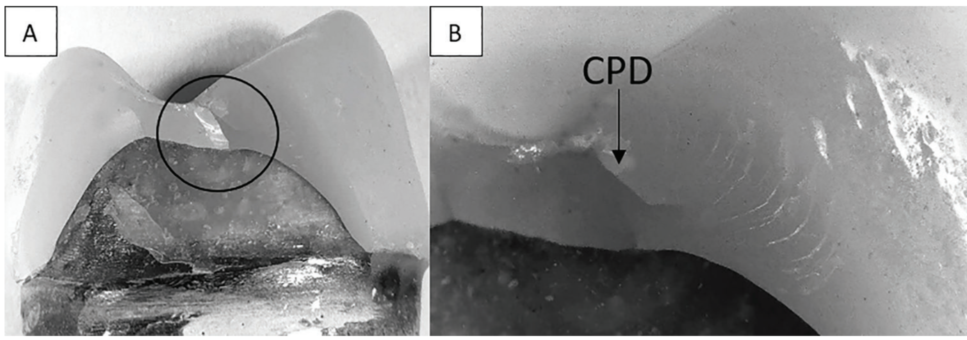

Fig. 2 Fractographic analysis. Digital stereomicroscopic images for the slight chamfer subgroups showed the crack originated from the occlusal surface of the restoration (circle) and the crack propagation direction (CPD; arrow) was toward the slight chamfer margin. (**A**) Nonapproximated view (×10). (**B**) Approximated view (×30).

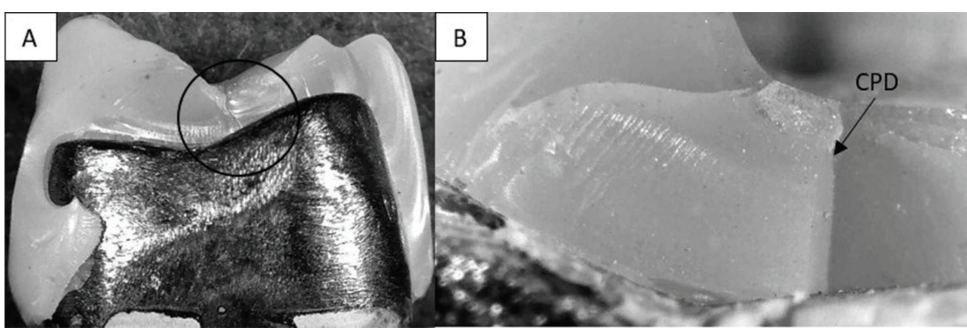

Fig. 3 Fractographic analysis. Digital stereomicroscopic images for the shoulderless subgroups showed the crack originated from the occlusal surface of the restoration (circle) and the crack propagation direction (CPD; arrow) was toward the occlusal surface of the die. (**A**) Nonapproximated view (×10). (**B**) Approximated view (×30).

The fractographic analysis of all subgroups showed a bulk fracture of restoration and cracks were originating from the occlusal surface of zirconia crowns (►**Figs. 2** and **3**).

Discussion

Several factors affect the resistance to fracture of the clinical crown such as the condition of loading, the elastic modulus of the supporting die, and the cementation.[12-14] A study stated that the elastic modulus of the supporting die affects the resistance to fracture of the fabricated crowns.[13] In this comparative study, the modulus of elasticity [E (GPa)] of the supporting nickel–chromium dies was $E = 200$ GPa in comparison with dentin $E = 18.6$ GPa and $E = 210$ GPa for zirconia.[14] Lower readings of the fracture resistance of crowns were recorded if the natural teeth or other die materials were used. Other two factors (cementation and loading condition) were the same for all the tested samples.

In this comparative study, the resistance to fracture of zirconia crowns in a monolithic design ranges from 1,632.9 to 3,992.5 N which depends on the margin design type and the selected occlusal thicknesses. Furthermore, this difference in these experimental variables (margin preparation design, design of the crown, and fabrication method) led us to the difficulty in comparison of the fracture resistance that was found in the literature to those found in this comparative study.[15]

Changing in the margin design has a significant influence on the resistance to fracture of monolithic zirconia crowns as shown in this comparative study; the shoulderless margin design failed at a load which was higher than the slight chamfer margin design when both of them had the same occlusal thickness. The 0.5 mm occlusal thickness for shoulderless margin design showed a higher fracture load than the 1 mm occlusal thickness for slight chamfer margin design despite the statistically no significant difference between them. This showed an agreement with the previous studies.[15,16] These favorable results were related with the manner of stress distribution through increasing the load on the crown in the shoulderless margin design as this force would be transmitted to the axial walls rather than the margin of the supporting die, resulting in stress concentration on the occlusal surface of the crown rather than the margin area as the fracture mode and the fractographic analysis revealed.[16] This result showed disagreement with another study[6]; this discrepancy could be related to the use of epoxy dies and the type of cement in their study. In contrast, the slight chamfer margin design carried the occlusal stresses which led to stress concentration on a small area of finish line rather than a wide area of occlusal surface which may lead to early failure of restoration as the mode of fracture and the fractographic analysis revealed.

The fracture resistance of monolithic zirconia crowns is significantly affected by the occlusal thickness which may increase survival of restoration as shown in the previous studies.[8,17] In this comparative study, when comparing the same preparation design groups, changing the occlusal thickness from 0.5 to 1 mm resulted in a significant enhancement of fracture resistance for the monolithic crowns.

Overall, results indicate that all monolithic crowns showed a fracture resistance higher than the maximum occlusal forces, therefore, both preparation designs were recommended and clinically may be successful, but the idea goes toward the preservation of a maximum amount of sound structure especially in periodontally treated cases.[18-20]

Previous studies have reported that the aging mechanism decreases the resistance to fracture of monolithic zirconia crowns.[21,22] In this comparative study, all the tested specimens were preserved in water at 37°C for 7 days and then exposed to thermocycling without cyclic loading, and finally subjected to static load to failure test. Therefore, this study provides limited information concerning zirconia's initial performance.

Conclusion

Within the limitation of the comparative study, shoulderless margin design has a more favorable outcome than a slight chamfer design in all thicknesses. Although the restoration with reduced occlusal thickness has lower fracture resistance than 1 mm occlusal thickness, the 0.5 mm restorations still can tolerate occlusal forces.

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Conflict of Interest
None declared.

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