Original Article

Marginal Fit of Full Contour Monolithic Zirconia in Different Thicknesses and Layered Zirconia Crowns

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ABSTRACT

Aim: Use of monolithic zirconia for fabrication of all-ceramic crowns eliminates several shortcomings of layered zirconia crowns. Long-term success of restorations highly depends on the marginal fit. The crown thickness is among the factors that affect the marginal integrity. Meanwhile, reduced thickness of crowns has several advantages such as preservation of tooth structure. The aim of this study was to evaluate the marginal fit of monolithic zirconia crowns in reduced thickness and to compare the marginal fit of full-contour monolithic zirconia in different thicknesses with layered zirconia crowns. **Materials and Methods:** In this *in vitro* study, two standard brass dies (7 mm × 5 mm length diameter) were prepared with a heavy chamfer finish line with 0.5 and 1 mm depth. By using a CAD-CAM system, 30 crowns were made in three groups (n = 10) of 1-mm thick layered zirconia, 1-mm thick monolithic zirconia, and 0.5-mm thick monolithic zirconia. Crowns were placed on master dies and randomly numbered. The marginal gap was measured on 18 points by using a digital microscope (×230). The mean ± standard deviation (SD) values were calculated and analyzed by Statistical Package for the Social Sciences (SPSS) software program through Kruskal–Wallis and Mann–Whitney tests (α = 0.05). **Results:** The marginal gap of 1-mm layered zirconia was significantly different from that of 1-mm monolithic zirconia (P = 0.001) and 0.5-mm monolithic zirconia (P = 0.004). Analysis of variance (ANOVA) revealed no significant difference between 0.5 and 1 mm thicknesses of monolithic zirconia (P = 0.141). **Conclusion:** Marginal gap in all the three groups was clinically acceptable. The two different thicknesses of monolithic zirconia crowns had no significant effect on the restoration marginal fit; however, layered zirconia crowns showed a significantly higher marginal gap than monolithic zirconia crowns.

Keywords: *CAD-CAM, layered zirconia, marginal fit, monolithic zirconia crown, thickness*

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Introduction

All-ceramic crowns are popular for dental restoration thanks to their splendid esthetic, biocompatibility, high strength, and metal-free structure.[1] Recently, prosthodontics benefits from the development of stronger and tougher ceramic materials such as yttria-stabilized tetragonal zirconia polycrystalline and their remarkable esthetic, excellent biocompatibility, low plaque accumulation, high strength, color stability, wear resistance, and thermal conductivity.[2]

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Conventional fixed zirconia prostheses were designed and milled in a one-piece zirconia substructure and veneering porcelain was directly fired onto the substructure to create a full-contour restoration.[3] Clinical failure of layered zirconia restorations mostly occurs due to chipping of veneering ceramic leading to compromised restoration.[4] Recently, full-contour monolithic zirconia crowns have alternatively replaced the veneered zirconia to overcome the major drawbacks of veneering zirconia copings.[5] They are superior due to their excellent flexural strength and toughness, acceptable tooth color and translucency, minimal wear on opposing teeth, conservative tooth preparation, durability, improved esthetic, and potential for long-term clinical success.[6,7] Yet, monolithic zirconia needs to be improved in terms of relative opacity, monochromatic appearance, and marginal adaptation after polishing and glazing.[8]

As monolithic zirconia has high flexural strength and fracture toughness, manufacturers recommend applying this material in reduced thicknesses.[9] Researchers suggested the minimum wall thickness of 0.4–0.5 mm and only 0.5 mm occlusal thickness for monolithic restorations.[10,11] Crowns of reduced thickness do not require deep preparation, and consequently more tooth structure can be conserved. Such a feature makes them suitable for a wider range of clinical indications. It is particularly, helpful in confined interocclusal space, and in preparation on the root surface.[12-14] In addition, monolithic zirconia has better translucency in lower thicknesses and in proper case selection a better esthetic result can be achieved.[15]

Long-term success of crowns highly depends on their marginal fit. As reported by previous studies, the marginal gap between 40 and 120 µm is clinically acceptable.[16,17] Great marginal discrepancies expose the luting material to the oral environment, resulting in cement dissolution and microleakage. Which can result in secondary caries, pulpal lesions, bone loss, and periodontal disease.[18] Poor marginal fit also decreases the fracture resistance and jeopardizes the restoration strength.[19]

Marginal fit is affected by several factors such as different preparation designs, fabrication methods, sintering techniques, and CAD-CAM systems.[20] One of the influencing factors is the material thickness.[21,22] Controversies exist about the effect of zirconia thickness on the marginal fit of zirconia-based crowns.[10,21,22] However, it can be clearly justified as shrinkage is a function of thickness; hence, the difference in thickness could result in different amounts of distortion and marginal gap.[23-25] This study was designed to evaluate the marginal fit of monolithic zirconia crowns in reduced thickness and to compare the marginal fit of full-contour monolithic zirconia in different thicknesses with layered zirconia crowns. The null hypothesis was that the marginal fit would not be different among monolithic zirconia crowns with different thicknesses and layered zirconia crowns.

Materials and Methods

Sampling criteria

Sample size was determined after statistical analysis of previous studies by a skilled statistician who was oriented with the subject. It was determined to be four specimens per group considering the different thicknesses of zirconia in the two groups (0.5 and 1 mm), with the effect size of 2 ($\alpha = 0.05$) and power = 80%. To increase the accuracy and due to adding one more group, 10 specimens were considered per group. Thirty crowns were fabricated in three groups ($n = 10$) as 1-mm thick layered zirconia, 1-mm thick monolithic zirconia, and 0.5-mm thick monolithic zirconia.

Setting and design

Institutional review board (IRB) approval was obtained for this *in vitro* experimental study (IR. SUMS.REC.1394.S1091). Two brass master dies [Figure 1] were designed and prepared by the CNC milling machine (CNC350; Arix Co. Tainan Hesin, Taiwan). Preparation was standardized by using a wide smooth continuous margin, free of any irregularities. Each die had 6º occlusal convergence angle, 7-mm axial occlusogingival height, and 5 mm diameter. The dies were prepared with heavy chamfer finish lines of either 1 mm or 0.5 mm. A ledge was considered at the occlusoaxial line angle to prevent rotation. The brass dies were visually inspected for any irregularities by a single operator using binocular loupes (Heine HR-C 2.5*; Heine, Herrsching, Germany). The measuring areas for evaluation of absolute marginal gap were marked as 18 grooves at 20° intervals with a high-speed handpiece (KaVo K9; KaVo dental GmbH, Biberach, Germany) and a diamond bur needle on a 2-mm groove below the margin. Thirty crowns were fabricated in three groups ($n = 10$) as 1-mm thick layered zirconia, 1-mm thick monolithic zirconia, and 0.5-mm thick monolithic zirconia.

Fabrication of the crowns

The master dies were coded and scanned with a laser scanner (3 Shape D810; 3 Shape, Copenhagen, Denmark) to digitize the dies. The data were transferred to computer software (3Shape; CAD Design software; 3Shape, Copenhagen, Denmark), which designed copings of 0.5 and 1 mm marginal thickness with

30-µm spacer considered 1 mm short of the finish line. Crowns were machined out of zirconium blanks (DD biozx2, Dental Direkt, Germany) which were made of 3Y-TZP-LA in a milling machine (CORiTEC 350i; imes-icore GmbH, Eiterfeld, Germany). Although the manufacturer permitted milling a minimum of 20 to 30 crowns with one milling bur set (CORiTEC 350i milling tools; imes-icore GmbH, Eiterfeld, Germany), each 10 crowns were milled with one bur set to be on the safe side. After being steam-cleaned, the specimens were sintered in a high-temperature sintering furnace (Sintramat; Ivoclar Vivadent, Schaan Liechtenstein) for 8 hours at 1500–1600°C. The machined specimens, which were designed to be 25% larger than master dies to compensate for the sintering shrinkage, reached the original size after sintering. The crowns obtained the desired physical properties through sinter firing. In the layered zirconia group, the copings were prepared for porcelain application (Vita VM9; Vident, Bad Sackingen, Germany). To make the veneers through the layering method, porcelain powder was mixed with the specified liquid. The obtained paste was applied over the frameworks by using a brush in a couple of stages. This technique included four sintering stages: base dentine washbake to achieve adequate bonding which was fired in furnace at 950°C, the first layer of dentine and enamel processed at 910°C, the second layer of dentine and enamel processed at 900°C, and glaze firing at 900°C (according to the manufacturer's instructions). Porcelain application and firing cycles of all copings were done by a single skilled technician up to current standard [Figures 2 and 3]. The final dimension of the restorations at the margin and occlusal surface was 1 mm for two groups and 0.5 mm in another group. Fabricated crowns were inspected and rejected in case of any imperfection

Marginal discrepancy evaluation

To measure the crown's marginal fit, the perpendicular distance was measured from the internal surface of restoration margin to the outermost edge of the preparation finish line (marginal gap according to

Figure 1: Brass master die

Figure 2: Monolithic zirconia crown

Holmes *et al.*[26]) [Figure 4] at 18 previously marked points. The measurements were done with a digital microscope (AM413FIT Dino-Lite Pro; Dino-Lite Electronic Corp, Taipei, Taiwan), which was mounted on a desktop stand(MS35B; Dino-Lite, Taipei, Taiwan), connected to a personal computer via USB 2.0 connection and photographed sequentially at ×230 magnification. High-resolution photographs were captured and displayed on the monitor [Figure 5], based on which measurements were repeated three times by a single investigator.

Statistical analysis

Having calculated the mean and standard deviation of collected data, the Kruskal–Wallis test was used to analyze the data. The three groups were compared by using Dunn's post hoc test ($\alpha = 0.05$). All statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS) software program, version 22.0 (IBM, Armonk, New York).

Results

The mean ± standard deviation (SD) marginal gap was 62.9 ± 15.2 µm in 1-mm layered zirconia, 42.3 ± 2.5 µm in 1-mm monolithic zirconia, and 45.4 ± 3.08 µm in 0.5-mm monolithic zirconia. The two thicknesses of

Figure 3: Layered zirconia crown

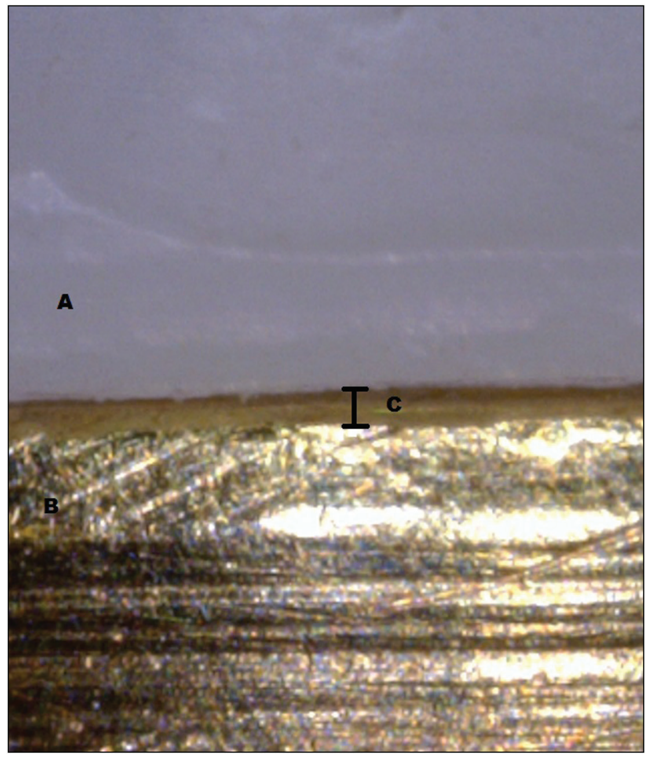

Figure 4: Marginal gap measurement: (A) zirconia crown, (B) brass die, and (C) measured vertical marginal gap

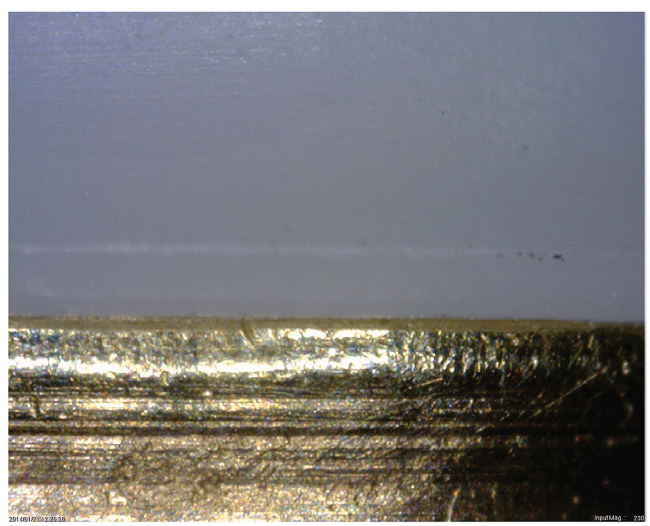

Figure 5: Captured images of crown–die interface

monolithic zirconia were not significantly different in terms of the marginal gap ($P = 0.141$). The highest mean marginal gap was observed in 1-mm layered zirconia specimens (62.9 µm), being significantly different from that of 1-mm thick ($P < 0.001$) and 0.5-mm thick monolithic zirconia ($P = 0.004$) [Tables 1 and 2].

Discussion

For full ceramic crowns, a marginal gap ranging from 1 to 165 µm is considered acceptable.[3,8,16,17] In this study, all the three groups had marginal gaps within clinically-acceptable range, indicating that both layered and monolithic zirconia (with 0.5 and 1 mm thicknesses) can be successfully used in the clinic.

Thickness of the ceramic material plays a critical role in stress distribution in the final restoration.[25] The residual stresses in restorations can be caused by the firing cycles and cooling rate during the veneering procedures. The stress released during cooling directly affects the material volume and causes restoration misfit.[27] Although the thermal behavior of core or veneering ceramic is multifactorial, the clinical design of zirconia must ensure sufficient thickness.[28] Jalalian *et al.*[21] evaluated the marginal fit of three different thicknesses of zirconia cores (0.3, 0.5, and 0.7 mm). Although their study showed no significant difference in the marginal fit of 0.3 and 0.5 mm core thicknesses, a significantly lower marginal gap was observed in 0.7 mm core thickness. Thus, they concluded that increasing the zirconia core thickness remarkably reduced the marginal gap of all-ceramic restorations. In this study, evaluating the marginal gap of two thicknesses of monolithic zirconia crowns (0.5 and 1 mm) revealed no statistically significant difference between the two groups. Therefore, we suggest that 0.5 mm thickness of zirconia can be safely used for esthetic purposes with no concern about the marginal fit of restoration.

The present results revealed the monolithic zirconia and layered zirconia crowns to be significantly different in terms of marginal fit. The higher marginal gap of veneered frameworks can have several reasons such as the firing shrinkage of veneering porcelain. Porcelain veneering includes melting of the porcelain particles, which further gather and fill the spaces. Shrinkage of the porcelain induces a compressive force on the coping and alters the gap size.[29] The coping deformation under the tension of contracting porcelain propagates along the margin circumference.[30] Furthermore, the veneering ceramic and zirconia substructure have different coefficients of thermal expansion, which causes tension pressure during cooling from glass transition to room temperature, and might affect the marginal fitness.[31,32]

Aboushelib *et al.*[33] reported that minimizing the thermal mismatch was desirable for all-ceramic layered zirconia restorations. According to Isgrò *et al.*,[34] even a zero thermal mismatch would not guarantee the compatibility between ceramic core and veneering porcelain. Furthermore, the fast cooling procedure, viscoelastic behavior of porcelain and repeated firing could cause distortion. Another reason for increasing misfit might be the number of firing cycles applied in conventional layering technique (at least 4). Studies revealed that repeated firings could change the coefficient of thermal expansion of core and veneer ceramic, and consequently yield unreliable thermal mismatch.[19,27,30,35]

Findings of this study were in line with Balkaya *et al.*[19] and Pak *et al.*'s studies,[31] which reported that firing of veneering porcelain affected the accuracy of different

Table 1: Mean rank, mean, and standard deviations of the marginal gap of the study groups (µm) measured by microscope

Groups		Layered zirconia	1-mm monolithic zirconia	0.5-mm monolithic zirconia
Mean rank		24.90	7.90	13.70
mean ± SD		62.9 ± 15.2	42.3 ± 2.5	45.4 ± 3.08
Median (IQR)		60.62 (19.09)	42.25 (4.04)	45.18 (6.54)
95%CI	Lower bound	51.71	40.56	43.26
	Upper bound	73.34	44.15	47.79

SD = standard deviation, IQR = interquartile range, CI = confidence interval

Table 2: Dunn's *post hoc* test for pair-wise comparisons of the tested groups

Groups*	Test statistic	Std. error	Std. test statistic	Sig. (*P* Value)	Adj. sig.**
1 versus 2	17.000	3.937	4.318	<0.001	<0.001
1 versus 3	11.200	3.937	2.845	0.004	0.013
2 versus 3	–5.800	3.937	–1.473	0.141	0.422

*Group 1: 1-mm layered zirconia, Group 2: 1-mm monolithic zirconia, and Group 3: 0.5-mm monolithic zirconia

**Adjusted for the number of comparisons using Dunn's *post hoc* test all-ceramic restorations. This was also approved by Castellani *et al.*[36] and Kohorst *et al.*,[37] who found that the veneering process significantly influenced the marginal fit of 4 unit pre-sintered zirconia fixed partial dentures. Hmedat and Ibraheem[35] noted that porcelain firing and glaze cycles affected the marginal gap. Contrary to the present findings, Sulaiman *et al.*[7] stated that veneering and glazing did not considerably affect the accuracy of different all-ceramic systems. This study also contrasted the studies conducted by Saraswathi *et al.*[38] and Komine *et al.*,[39] which detected no significantly different marginal gaps between the full zirconia and layered zirconia crowns. They attributed this to the strength of zirconia.

In this study, machined brass die was used as an abutment. Several investigators used metal dies to measure the marginal gap.[32,40,41] Among the advantages of metal dies are standardized preparation, and lack of wear during manufacturing process and measurement. There are various methods for measuring marginal adaptation, the most frequent ones are direct microscopic view, cross-section, and replica techniques.[20] This study evaluated the marginal gap by using a direct microscopic view of the non-cemented specimen on a die. This technique is noninvasive and the marginal gap could be measured in numerous points; nonetheless, the internal gap could not be assessed.

One of the major limitations of this study was the impossibility of measuring the horizontal marginal gap and internal fit through this observational design, as it required cementation and sectioning of specimens. Moreover, the specimens were not subjected to artificial aging, and oral conditions were not simulated through thermal cycling and applying mechanical loadings. The copings were all created and tested under ideal conditions, which is sort of impossible in clinical conditions. In addition, measuring human natural teeth would yield more reliable results than the brass dies. Further investigations are needed to measure both the marginal and internal fits and evaluate the influence of aging, different tooth preparation designs, and fixed partial dentures on the margin distortion, as well as the influence of cementation technique on the marginal and internal fit of zirconia restorations.

Conclusion

Within the limitations of this *in vitro* study, it can be concluded that layered zirconia, 0.5-mm and 1-mm thick monolithic zirconia crowns have clinically acceptable marginal fit. It can also be concluded that different thicknesses of monolithic zirconia crowns do not significantly affect the marginal fit. Thus, lower thicknesses of monolithic zirconia crowns can be safely used without affecting the marginal fit. In addition, layered zirconia crowns showed a significantly higher marginal gap than monolithic zirconia crowns.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

Authors contributions

Not applicable.

Ethical policy and institutional review board statement

Not applicable.

Patient declaration of consent

Not applicable.

Data availability statement

Not applicable.

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