Original Article

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The effect of monolithic zirconia crown dimension on the accuracy of fit

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Objective: To investigate the influence of monolithic zirconia crown dimension on the accuracy of marginal and internal fit

Materials and Methods: Four titanium models with various dimensional preparations were constructed. The general designed characteristics were circumferential deep chamfer finish line, round internal line angle, 12° of total occlusal convergence and 10 mm diameter at the margin. For group 1 and 2, the abutment was designed in order to get 1-mm and 2-mm uniform crown thickness, respectively. For group 3, the abutment was designed to get 1-mm thickness at axial wall and 2-mm thickness at occlusal wall, and, conversely, for group 4, the abutment was designed to get 2-mm thickness at axial wall and 1-mm thickness at occlusal wall. Forty identical external contour crowns were fabricated with Ceramill system (n= 10). Replica technique was used to examine marginal gap, absolute marginal discrepancy and additional 3 locations of internal gap: mid-axial wall, axio-occlusal angle and mid-occlusal area. The data were analyzed using One-way ANOVA and Turkey's test at a significance level of 0.05.

Results: There were significant differences of gaps at most locations, except axial area ($p<.05$). The mean ± SD of marginal gaps were 27.9±5.4 μm, 32.8±6.8 μm, 32.6±7 μm and 22.3±4.2 μm for group 1, 2, 3 and 4, respectively. The mean ± SD of absolute marginal discrepancies were 131.5±11.7 μm, 111±15.6 μm, 114.5±15.8 μm and 125.9±9.7 μm for group 1, 2, 3 and 4, respectively. The highest internal gap was found at occlusal area in all groups.

Conclusion: The thickness of translucent zirconia crown influenced the marginal and internal fit. Occlusal wall thickness could affect the marginal gap, absolute marginal discrepancy and internal gap despite crown's axial wall thickness. Thicker occlusal wall could result in lesser absolute marginal discrepancy and occlusal internal gap, but greater marginal gap. However, the marginal gap in all groups was obviously, clinically acceptable. Therefore, appropriate occlusal crown thickness should be fabricated to avoid unpredictable stress that affected crown fitness and to prevent the fracture of the crown clinically.

Keywords: Absolute marginal discrepancy, Gap, Translucent, Zirconia

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Introduction

Zirconia is a type of polycrystalline ceramics, which has numerous promising physical and mechanical properties and excellent biocompatibility. [1] At ambient pressure, three crystallographic shapes are present at different temperatures. The monoclinic form is present at room temperature and upon firing to 1170°C. At 1170°C-2370°C, the structure of zirconia is tetragonal; and between 2370°C to the melting point, zirconia changes into cubic phase. [2] After full sintering of zirconia and while the temperature is cooling down, zirconia spontaneously transforms back from cubic to tetragonal phase and finally to a stable monoclinic phase. The change from tetragonal phase to monolithic phase causes volume increase by approximately 4.5%. [2] Since it is desirable to

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maintain zirconia in tetragonal phase at ambient condition, many metallic oxides such as CaO, MgO, Y_2O_3, and CeO_2 have been used as phase stabilizer at room temperature. Currently, Y_2O_3 stabilized tetragonal zirconia polycrystal is the most widely used in dental ceramic material for the following desirable characteristics: high fracture toughness, high thermal resistance, low thermal conductivity, and chemical resistance. [1]

As aesthetic metal-free restorative materials are in high demand among patients, zirconia is extensively used [2] for the fabrication of both anterior and posterior fixed dental prosthesis. Additionally, computer-aided design and computer-aided manufacturing (CAD-CAM) makes it a feasible material for dental application; thus, it has rapidly gained popularity.[3] At present, there are two methods to fabricated zirconia prosthesis. Zirconia can be milled from the fully sintered block, which does not require further sintering to avoid shrinkage of the final restoration. However, it has drawbacks, such as rapid wear of milling tools and longer time consuming of milling process. Another faster method is to mill from pre-sintered zirconia block; nevertheless, in order to get an optimum fit of the restoration after the final sintering process, the shrinkage of the block needs to be calculated precisely.

Zirconia was initially used as an alternative to metals for a core of a crown in both posterior and anterior regions because of its white color and high strength. It can preserve color of the gingiva due to its inertness, biocompatibility[1] and whitish color.[4] As zirconia is originally opaque white, glass veneer is normally used to sinter on top of the opaque core in order to create bilayered zirconia restoration so the negative aesthetic effects can be overcome. However, one of the most frequent complications of zirconia crowns is the delamination of the veneering glass. [5] Consequently, zirconia crowns with chipped porcelain have to be repaired or replaced to resume function and aesthetics. To overcome this problem, manufacturers have recently launched monolithic zirconia restoration.

Monolithic zirconia restoration is well known for its high strength. However, its opacity initially causes the aesthetic problem. The opacity of conventional zirconia is resulted from, first, the high mismatch of different refractive index between grain particles and the matrix. [6] The three forms of zirconia- monoclinic, tetragonal and cubic- also influence the refractive index. Secondly, the common size of zirconia's grain (approximately 0.4 μm in diameter) that interacts with the incident light wavelength (approximately 0.4-0.7 μm) is also another cause of zirconia's opacity. [7] In order to solve the inferior optical properties of opaque zirconia, novel monolithic translucent zirconia have been introduced. Methods of microstructural modifications have further improved its translucency which, currently, can be divided into four alternative approaches. [6] The first method is to increase the grain size of the particle in order to decrease the number of grain boundaries, resulting in less light scattering at the grain boundaries. [8] However, with this mean, the strength of the zirconia will decrease drastically, and the low temperature degradation (LTD) also rises when the grain size is larger than 1 μm. [9] The second method, on the other hand, is to reduce the grain size (approximately 0.1 in diameter). [7] The strength attained from reduced grain size zirconia is still questionable as the effect of stress-induced transformation toughening may disappear. [10] The third way is to increase the amount of zirconia in cubic phase by adding more the yttria dopant. If the amount of yttria is high, zirconia will be more translucent. The last approach is to purify zirconia. [11]

Clinically, there are many factors contributing to a successful long-term crown restoration, including marginal and internal fit. Marginal leakage can cause many problems, for example dental plaque accumulates at the defective margin of the restoration and leads to gum disease and dental caries. [12-14] The internal fit provides the retentive and resistant forms of the crown. [15] In addition, large internal gap at the occlusal area means a thinner than expected restoration that may compromise the strength of the restoration or this may require additional tooth preparation to achieve desired crown thickness. Thus, proper internal and marginal adaptations are crucial factors for the longevity of a restoration.

There are various factors that influence the accuracy of CAD-CAM prosthesis, such as scanning process, software, and sintering stage of zirconia blank. After sintering the pre-sintered block or green block of zirconia at high temperature, it will subsequently shrink, become dense and gain more strength. CAD-CAM system is used to adjust the size of shrunk zirconia to obtain the optimum fit of a prosthesis.[2] Previous studies have shown that both the size and design of the substructure, the zirconia block stage, and CAD-CAM system could affect the prosthesis adaptation. [15-19] It was found that for a bridge substructure, the influence of post sintering shrinkage distorted the axial wall of abutment substructure, especially at the pontic side. [16] Moreover, the design of crown preparation such as type of marginal preparation [17] and occlusal surface preparation [19] also influences the marginal fit of CAD-CAM zirconia prosthesis. The size of the tooth also has an impact on marginal gap. For example, premolar tooth has smaller marginal gap compared with that of molar tooth. [18] The largest gaps have been typically found at the occlusal area that are larger than the set value and could have been due to anisotropic shrinkage of zirconia blanks subjected to post machine sintering. The sintering shrinkage in the horizontal axis was found to be greater than that in the tooth axis.[16] Furthermore, this shrinkage was not isotopically uniform, and its rate of shrinkage was frequently not equal to what the manufacturer provided.[20] Another study also found that the precision of the manufacturer's recommended parameters for the CAD-CAM system setting was not accurate, especially at the occlusal area. The gap tended to be greater than the setting value.[18] A linear sintering shrinkage of the zirconia block relies on the density of zirconia blocks, and the accuracy of the restoration gap is dependent on the property of linear shrinkage. The higher the density of the block was, the lower the linear sintering shrinkage would be, which would result in an accurate prosthesis with better adaptation. [21]

Nevertheless, there have been only few studies on the marginal and internal fit of monolithic translucent zirconia crown. Moreover, there is no available data on the shrinkage pattern of non-uniform thickness of monolithic translucent zirconia crown. Most of the studies found that the largest gap is observed at the occlusal area in both monolithic zirconia crowns [22] and zirconia copings. [18, 21] Since the shrinkage of zirconia might be affected by the crown thickness and its anisotropic shrinkage property, the objective of this study was to investigate the influence of post sintering shrinkage on various thickness of crown at occlusal and axial area, which consequently affects the internal and marginal adaptation.

Materials and Methods

Four standard abutment models were milled from titanium alloy. They were designed by TopSolid 2014 program with the following general abutment preparation design: circumferential deep chamfer finish line, round internal line angle, total occlusal convergence of 12° and 10 mm diameter at margin. Standard abutment models with four different preparation designs were fabricated. For group 1 and 2, the abutments were designed in order to get uniform crown thickness of 1 mm and 2 mm, respectively. For group 3 and 4, the abutments were designed to attain different thickness at occlusal and axial wall. For group 3, crown thickness was 2 mm at the occlusal wall and 1 mm at the axial wall, while for the group 4, the crown thickness was 1 mm at the occlusal wall and 2 mm at the axial wall (Figure 1).

For the fabrication of crowns, Ceramill CAD-CAM systems were used. Each model was scanned by a 3D scanner (Ceramill Map 400, Amann Girrbach, Koblach, Austria), and CAD design software (Ceramill Mind, Amann Girrbach, Koblach, Austria) was used to design identical external contour crowns (n=10). No cement space at the margin with an additional cement space of 50 µm starting 1 mm above the finish line was set according the manufacturer's recommendation. The designed crown data were transmitted to CAM software (Ceramill Motion, Amann Girrbach, Koblach, Austria) and simulated crowns were milled from partially sintered translucent zirconia discs (Ceramill Zolid FX White, Amann Girrbach, Koblach, Austria) in a five-axis milling machine (Ceramill Motion2, Amann Girrbach, Koblach, Austria). The crowns were sintered in a furnace (Ceramill Therm3, Amann Girrbach, Koblach, Austria) with the firing cycle recommended by the manufacturer. When the temperature reached 1450 °C, it was maintained for 2 hours before gradually cooling down. The overall sintering time took 7 hours and 50 mins. A single experienced laboratory technician controlled the entire CAD-CAM processes.

The marginal and internal fits of the crowns were examined using silicone replica technique. Low-viscosity silicon impression material (Express XT, 3M ESPE, St. Paul, MN, USA) was loaded in the fitting surface of the crown. The crown was seated on titanium model using 50-N load. [18] After the low-viscosity silicon completely polymerized, the crown was removed from the model. Subsequently, high-viscosity polyvinyl siloxane (Express XT, 3M ESPE, St. Paul, MN, USA) was loaded in a printed customized acrylic plastic tray to stabilize the low-viscosity polyvinyl siloxane. The replica of the model was sectioned into 2 equal parts by using a sharp razor blade at the reference cutting slots on the customized plastic tray as a cutting guide (Figure 2).

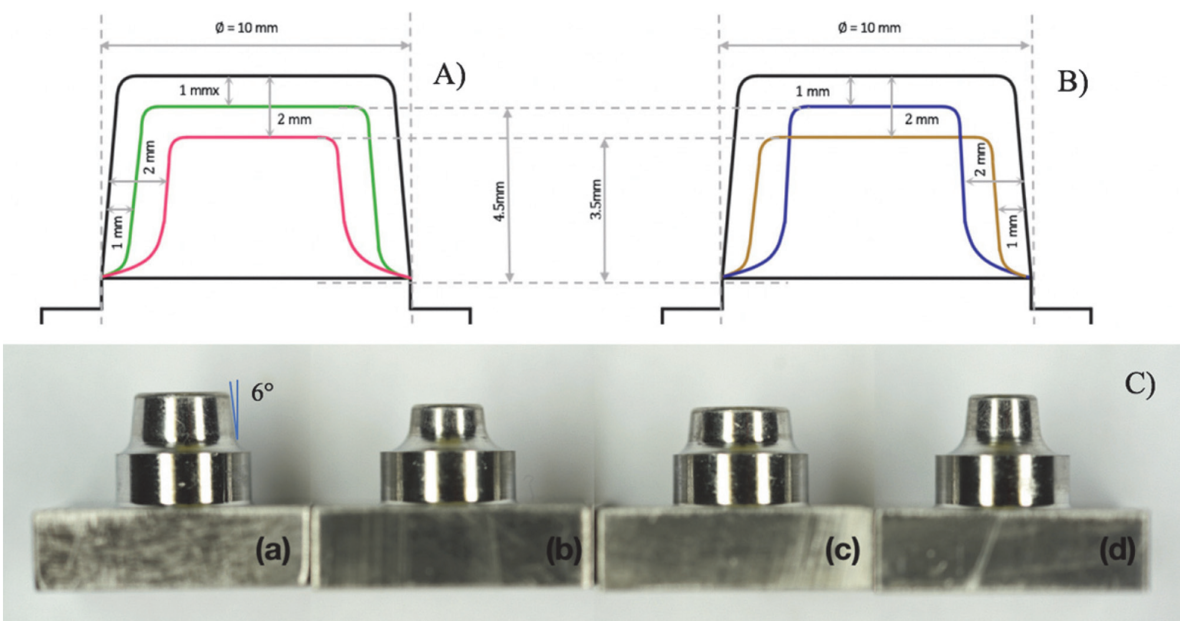

Figure 1 Illustrations of design of abutment models and crowns; (A) black line shows the external contour of the crown, green line shows the design of group 1 abutment, pink line shows the design of group 2 abutment, (B) black line shows the external contour of the crown, brown line shows the design of group 3 abutment, blue line shows the design of group 4 abutment; and (C) a photograph of titanium abutment models; (a) group 1, (b) group 2, (c) group 3, and (d) group 4

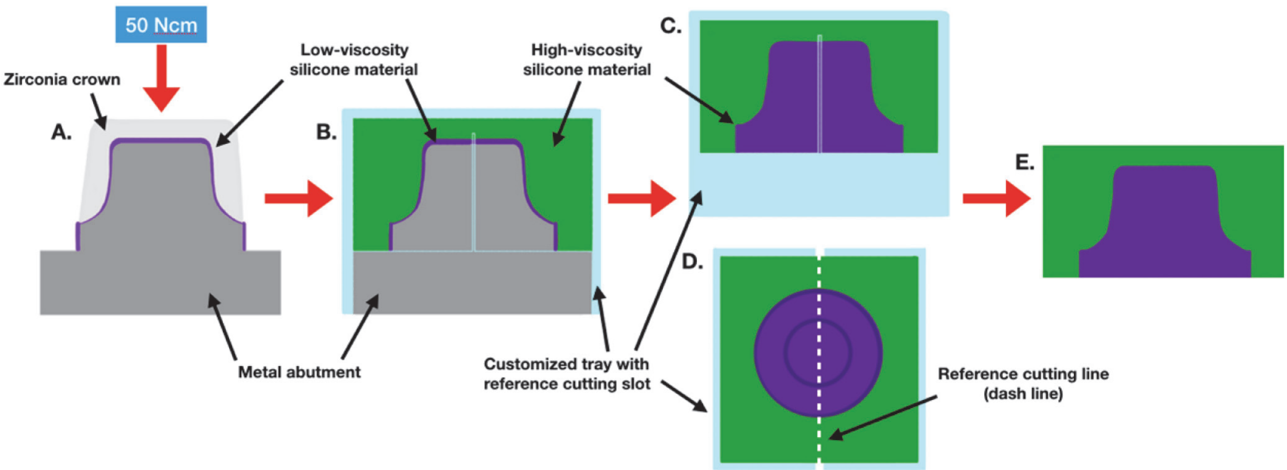

Figure 2 Schematic diagram of the replica technique using silicone material; (A) a low-viscosity silicone material is loaded in the inner surface of the crown and the crown is seated on the abutment. (B) The crown is removed. A high-viscosity silicone material is loaded in the customized tray, and the tray is put on the abutment. (C) The tray with silicone material is removed. (D) The bottom view of the tray with silicone, (E) The half of silicone replica.

One half of each replica was observed under an optical microscope at a magnification of 50X. The replica image was taken by a digital camera (Nikon eclipse E400 POL, Japan) and all replica images were collected. The gaps were measured using the image analysis software (ImagePro® Plus software v.7.0, Media Cybernetics, MD, USA). The measurement was made at nine specific locations per specimen (1 point at mid occlusal (O), 2 points at the axial–occlusal transition angle (A1, A2), 2 points at mid axial wall (AX1, AX2), 4 points at the margin (MG1, AMD1, MG2, AMD2)) (Figure 3, 4). The marginal fit were measured as absolute marginal discrepancy (AMD) and marginal gap (MG) according to Holmes et al. (1989)'s definition. [23] The marginal gap was the perpendicular distance from the internal surface of the crown to the edge of the finish line; and the absolute marginal discrepancy was the measurement from the edge of the crown to the finish line. The internal gap was the perpendicular measurement from the internal surface of the crown margin to the axial wall of model abutment. The average of marginal gap, absolute marginal discrepancy, axial internal gap and axio-occlusal internal gap values between left and right side of the specimen was represented as the specimen gap value.

The obtained data were analyzed using one-way ANOVA to determine whether there was a significant difference between four groups in terms of the internal and marginal adaptations. In addition, a Turkey's test was carried out for further analysis between each group and the location of gap measurement. The significant level was set at $\alpha < 0.05$ (SPSS version 21, Armonk, NY, USA).

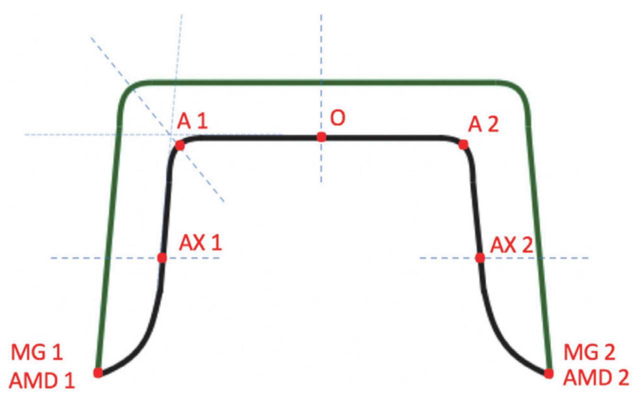

Figure 3 Locations of marginal and internal gaps measurement

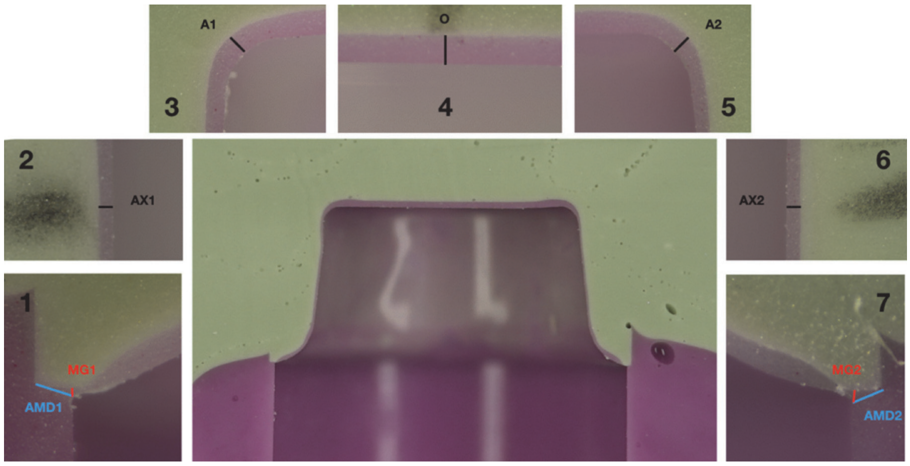

Figure 4 Schematics of gap measurement locations at 50X magnification (1)&(7) Marginal area, (2)&(6) Axial wall, (3)&(5) Axio-occlusal angle, (4) Occlusal area

Results

The means and standard deviations of all gap values of various thickness are presented in Table 1. The maximum and minimum gap values of all groups are shown in Table 2. One-way ANOVA and Turkey HSD showed that the crown thickness significantly affected the internal and marginal gaps at some locations ($p < .05$) (Table 1). In the marginal fit evaluation, the MG of group 2 and 3 were greater than that of group 4 ($p < .05$). For absolute marginal discrepancy, it was found that the AMD of group 2 and 3 were lower than that of group 1 ($p < .05$). No underextended margin was observed in all groups. For the internal fit evaluation, no difference was found among 4 groups regarding the axial internal gap. The largest internal gaps of all groups were found at occlusal area. For occlusal internal gap, the occlusal gaps group 2 and 3 were lower than that of group 4 ($p < .05$).

Table 1 Mean (standard deviation) in μm of the gap width compared among various thickness of monolithic crowns

Group	Group 1	Group 2	Group 3	Group 4
Thickness ratio (occlusal: axial) (mm)	(1:1)	(2:2)	(2:1)	(1:2)
N	10	10	10	10
MG	27.9(5.4) ^{ab}	32.8(6.8)^{a}	32.6(7.0)^{a}	22.3(4.2)^{b}
AMD	131.5(11.7)^{c}	111.0(15.6)^{d}	114.5(15.8)^{d}	125.9(9.7)^{cd}
Axial internal gap	62.8(6.8)^{e}	60.0(5.9)^{e}	57(7.0)^{e}	60.0(8.5)^{e}
Axio-occlusal internal gap	120.3(15.5)^{fg}	106.8(11.2)^{f}	112.5(12.5)^{fg}	122.1(12.0)^{g}
Occlusal internal gap	171.6(6.8)^{hi}	164.5(7.9)^{h}	166.2(4.5)^{h}	179(7.6)^{i}

The values with the same superscript are not significantly different ($p \geq .05$)

Table 2 Descriptive data: Maximum and minimum gap values (μm)

Group	Group 1		Group 2		Group 3		Group 4	
Thickness ratio (occlusal: axial) (mm)	(1:1)		(2:2)		(2:1)		(1:2)	
	max	min	max	min	max	min	max	min
MG	36.8	20.7	41.2	23.7	43	17.6	29	15.7
AMD	148	110.9	136.1	92.3	141.3	85.5	139.1	113.6
Axial internal gap	73.7	55	67.8	48.9	67.6	48.6	77.45	51
Axio-occlusal internal gap	148.4	95	121.5	90	128.4	86.2	143.5	103
Occlusal internal gap	180.6	161.5	173.8	145.5	171.8	159.6	190.4	163.6

Discussion

In this study, the significant differences were found in the internal and marginal gaps of monolithic translucent zirconia crown with varying dimensional thickness, except the internal gap at the axial wall. Therefore, the null hypothesis was rejected. Majority of the literature suggested that the marginal gap below 120 μm is clinically acceptable. [15, 17, 18, 24, 25] For all-ceramic restorations manufactured by CAD-CAM technology, the mean marginal gaps ranged from 23 to 83 μm. [26-29] The definition of the marginal gap width and the techniques used in measuring the gap were different in various literatures. Therefore, such heterogeneities must be taken into consideration when comparing the values of the gap width in different studies.[30] In this study, the definition of internal gap, marginal gap and absolute marginal discrepancy proposed by Holmes et al. was followed. [23] The result of this present study revealed that the marginal gaps were not statistically different between the two groups with identical occlusal wall thickness regardless of its axial wall thickness. The crown with 1-mm thickness at the occlusal could result in lesser marginal gap than the crown with 2-mm thickness at the occlusal. This was probably due to the larger occlusal gap that could be found in the crown with 1-mm thickness at occlusal comparing to the crown with 2-mm thickness at occlusal. The larger occlusal gap could facilitate the seating of crown as increased cement space improved vertical marginal discrepancy.[31] However, the highest value for mean marginal gap was 43 μm, which was considered a good marginal adaptation according to clinically accepted value in previous studies. [15, 17, 18, 24, 25] The absolute margin discrepancy value was higher in case that the margin was overextended or underextended. In this study, the high absolute marginal discrepancy value was due to the overextended margin since there was no underextended margin found. Mean of absolute marginal discrepancy in group with 1-mm thickness at occlusal wall, group 1 and 4, was higher than 120 μm. Despite the difference in crown thickness at axial wall, 2-mm thickness at occlusal wall of the crown produced better adaptation in terms of absolute marginal discrepancy compared with 1-mm crown thickness. This could be the result of the anisotropic shrinkage after sintering of pre- sintered zirconia blank. [16] Lower shrinkage could be found in thicker zirconia at occlusal wall especially in horizontal axis. However, the maximum absolute marginal discrepancy values presented in all groups were also slightly higher than that of clinically acceptable value. [15, 17, 18, 24, 25] From a clinical point of view, the overextended margin could be adjusted clinically or in the working cast before delivery to the patient.

Poor internal adaptation can affect the retention and fracture strength of the crown. Ideally, the cement gap must be uniform and as thin as possible. [32] An in vitro study reported that a thin cement layer of 80 μm at the occlusal area was suitable for the mechanical strength of the zirconia restoration. [33] In this study, the cement gap was set at 50 μm uniformly as recommended by the company. However, the results showed that the gap width was generally larger than 50 μm without homogeneity. Generally, the widest gap was found at the occlusal surface area and became narrower towards the crown margin. This trend was in the accordance with the previous studies. [22, 29, 34]

There are many factors affecting the accuracy of restoration produced by CAD-CAM technique; including the manufacturing process such as scanning process, software, and type of milling machine; the sintering stage of zirconia blocks; ceramic firing effect; and preparation design of the crown. In this study, all possible aforementioned factors were controlled except the thickness of the crown which was varied. One study found that the thicker the zirconia core was, which, in this case, were 0.3, 0.5 and 0.7 mm, the smaller the marginal gap would be. [35] In this study, there was no significant difference in the marginal gap between groups of 1-mm and 2-mm uniform thickness of crowns. However, significant difference was found in terms of the absolute marginal discrepancy. The absolute marginal discrepancy of 1-mm thick crown was significantly larger than that of 2-mm thick crown. This could be owing to the reduction of the internal stress in bulk marginal area of zirconia crown, resulting in a better marginal adaptation. [36] Therefore, thicker zirconia crown would result in a better marginal adaptation in a single crown. Currently, there have been no other studies that focused on the gap of non-uniform crown thickness. Thus, it was not possible to compare the result of the current study with other studies. Nevertheless, the marginal fit seemed to be clinically acceptable in all groups as mentioned above. On the contrary, the internal fit values were not precise, especially in the occlusal area. The gap at occlusal area in all groups was approximately 3 times higher than the set cement gap value. Comparing between the two groups with identical occlusal wall thickness, occlusal gaps were not significantly different. For groups with 1-mm thickness at axial wall but different occlusal wall thickness, the occlusal gaps did not differ. However, there was a significant difference in occlusal gap between the two groups of similar 2-mm thickness at axial wall with different occlusal wall thickness. The difference could be the result of unequal shrinkage between two different levels of thickness in non-uniform crown. The crown, which has thinner occlusal wall than its axial wall, could contribute to a larger gap at the occlusal area. Clinically, fracture of monolithic zirconia crowns can still be found even though ideal preparation for adequate thickness was performed. [37] This crown fracture is probably caused by the increase of final cement gap, especially at occlusal surface, which resulted in diminished material thickness after occlusal adjustment. Dimensional accuracy of the pre-sintering stage zirconia block is calculated using a software, where the shrinkage of the pre-sintering block after sintering is approximately 25%.[30] The non-homogenous internal gap as found in the result of this study could be caused by non-uniform shrinkage of the zirconia material. A previous literature also showed that the sintering shrinkage of zirconia lacked uniformity, and depended upon the zirconia specimen's shape. [20] Furthermore, a smear layer of flakes and wear debris together with a large amount of microcracking caused by cutting path while machining the partially sintering zirconia could be another cause of misfit of the milling restoration.

There are two common ways to assess the marginal and internal fit of direct restorations- direct and indirect methods. However, there is no standard protocol in evaluating the fit of a restoration. The benefit of indirect technique is that it is a non-destructive methodology. One of the indirect techniques is using a Micro-CT to measure the gap. The drawbacks of this technique are artificial defect from the reflection of the radioactive rays that could be shown in a radiographic image, and the resolution of the micro-CT is poor. Another frequently used indirect method is the replica technique [18, 29, 34], which is comparatively less expensive. However, the thin silicon film representing the gap can be easily damaged; therefore, careful removal of the crown from the silicone impression material is critical to avoid its tearing. Since both assessment techniques are considered to be acceptable for measuring internal and marginal fits [34], the replica technique was used in this present study. In addition, the 50 N load was used because, in the previous study [18], it was demonstrated that there was no difference of the measured gaps between the specimen with the low-viscosity impression material and the specimen without impression material.

Conclusions

1. The thickness of translucent zirconia crowns influences the internal and marginal fitness. Adequate crown thickness at occlusal wall could provide monolithic translucent zirconia crown with minimal absolute marginal discrepancy and occlusal internal gap. The marginal gap in all groups was, however, within the clinically acceptable range.

2. The internal gaps, especially at the occlusal area, were much greater than the set cement gap value. The greater occlusal gap was found especially in 1-mm thickness of the crown at occlusal, and this may reduce the strength of the restoration. To prevent the fracture of monolithic translucent zirconia crown, optimal thickness at occlusal wall is required.

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