Effect of occlusal groove on abutment, crown thickness, and cement-type on fracture load of monolithic zirconia crowns

Yu TSUYUKI1,2, Toru SATO1, Syunataro NOMOTO1, Mamoru YOTSUYA1, Teruyoshi KOSHIHARA1, Shinji TAKEMOTO2,3,4 and Masao YOSHINARI3

1 Department of Fixed Prosthodontics, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061, Japan
2 Oral Health Center, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061, Japan
3 Department of Dental Materials Science, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061, Japan
4 Department of Biomedical Engineering, Iwate Medical University, 2-1-1 Nishi-tokuta, Yahaba-cho, Shiwa-gun, Iwate 028-3694, Japan

Corresponding author, Shinji TAKEMOTO; E-mail: takemoto@tdc.ac.jp, takemoto@iwate-med.ac.jp

The aim of this study was to investigate the effects of occlusal form of abutment, occlusal thickness of monolithic zirconia crowns (MZC), and cement type on the fracture load of MZC. Abutments were prepared with 2 types of occlusal forms: groove-type and flat-type. These were designed so that thickness at the central fissure region of MZC was 0.3, 0.5, or 0.7 mm. Glass ionomer cement and resin cement were used to lute MZC to their corresponding abutment. Fracture load was determined using a universal testing machine. As a result, groove-type abutment had lower fracture load compared to flat-type abutment; however, the decline in strength was smaller when resin cement was used. Additionally, specimens with larger occlusal thickness had greater fracture load regardless of groove or cement-type. The fracture of MZC occurred on the central fissure region of MZC except for 0.7 mm groove-type MZC luted with resin cement.

Keywords: Zirconia crown, Fracture load, Abutment form, Luting cement

INTRODUCTION

Metals have been used for posterior crown restorations as a material with excellent marginal adaptation accuracy and mechanical properties to withstand occlusal forces. However, in recent years, metal-free restorations have received more attention due to an increase in demand for aesthetic restorations. All-ceramic restorations (ACR) using computer aided design and computer aided manufacturing (CAD-CAM) technology are becoming a common form of restoration due to their comparatively high precision and low risk of allergic reactions.

Conventional ACR are fabricated by veneering porcelain on ceramic coping. Ceramic copings are more brittle than metal crowns; thus substantial thickness of material is required leading to greater reduction of tooth structure during preparation. Cases of veneer chipping on ceramic coping was reported to occur 7% higher compared to metal copings. As a solution to prevent veneer chipping, monolithic ceramic restorations are becoming desired as a choice for restoration.

Yttria stabilized tetragonal polycrystalline zirconia (TZP) is used for ACR coping material because the bending strength is higher than conventional porcelain. TZP is white and lacks translucency, therefore, ceramic veneering was required in order for the restoration to resemble natural teeth. In recent years, TZP with improved translucency and color have been introduced; reports have shown that translucent TZP and conventional TZP possess equal strength. This development has increased the scope of application of TZP crowns as monolithic zirconia restorations in regions of high aesthetic demand.

Preparation for conventional ACR, which is veneered with porcelain on coping, requires considerable amount of tooth reduction to ensure restoration thickness for sufficient strength. The occlusal thickness of monolithic zirconia restoration is a primary factor which influences stress and fracture resistance. TZP possesses superior fracture resistance, therefore the required occlusal thickness for monolithic zirconia restoration is 0.5 mm compared to 1.5 mm for conventional ACR. The restoration becomes readily thin near the central pit due to the ridges designed on the inner slope on the crown. Complex distribution of stress applied to the central pit region could lead to fracture, however, the effects of occlusal thickness in the central pit region of monolithic zirconia restoration on its fracture resistance has not been adequately studied.

Occlusal reduction in preparation for ACR increases overall tooth reduction and decreases abutment tooth height. Tooth preparation is known to affect the strength and retention of crown restorations. Therefore, in order to obtain acceptable retention and clearance, minimal tooth reduction and sufficient abutment tooth height are required. The addition of groove, ridge, and cavity are recommended as preparation forms to increase crown retention. Occlusal groove on abutment can increase occlusal clearance and adhesive surface area while maintaining abutment height. Moreover, adequate height of axial walls promotes crown retention. However, the effects of adding occlusal groove on abutment, in order to guarantee clearance, on the fracture strength of monolithic zirconia restoration have not been investigated.

The type of luting cement has shown to influence...
the distribution of stress generated on the tooth-crown complex which affects its integrity\(^7\). Therefore, a strong bond between tooth and ACR improves the brittle nature of ceramics\(^10\). Currently, adhesive resin cements are recommended for bonding ACR during placement. However, adequate isolation and multiple pretreatment steps are required for proper bonding using resin cement\(^11,12\). TZP is a high-strength ceramic on its own and it has been reported that conventional methods (i.e., glass ionomer cements) provide adequate adhesion\(^11-14\); however, information on the effect of cement types on the fracture strength of monolithic zirconia restoration is inadequate.

This study investigated the effects of occlusal groove on abutment, crown thickness, and two types of cements on the fracture load of monolithic zirconia crowns.

**MATERIALS AND METHODS**

*Fabrication of metal abutments*

Custom abutments, assuming the mandibular first molar, were fabricated with stainless steel (SUS303). ACR tooth preparation guidelines were followed for abutments design: 1.0 mm deep chamfer at margin, taper 6° between tooth axis and lateral wall, and 1.0 mm curvature radius. Two types of occlusal forms were prepared: groove-type with a mesiodistal groove and flat-type with no groove. Figure 1 shows the illustration of abutments. Groove-type abutments had a height of 5.3 mm, and groove with depths of 0.3, 0.5, or 0.7 mm. The groove had a curvature radius of 1.6 mm assuming the width of diamond burs used during tooth preparation. Flat-type abutments were prepared at heights of 5.0, 4.8, and 4.6 mm.

*Fabrication of MZC*

Crown design was performed using an image measuring system (NEXIV VMR-3020, Nikon, Tokyo, Japan) to quantify abutment dimensions. Each abutment was designed a simple corresponding MZC where crown thickness at the central pit region was standardized (Figs. 1 and 2(a)). Depending on the abutment height and groove depth, MZC thickness at the central pit was 0.3, 0.5, or 0.7 mm. Cement space was established at 30 μm. The design blueprint was saved as STL file format. Six types of MZC, for a total of 60 (n=10) crowns were milled from pre-sintered translucent TZP blocks (ZIRCONIA DISK, Adamant, Tokyo, Japan) using a milling machine (DWX-50, Roland DG, Shizuoka, Japan). MZC were sintered using an electric furnace (S7-2035D, MOTOYAMA, Osaka, Japan) which was heated from room temperature to 1,450°C at 5°C/min, held for 2 h, then cooled down. After the fabrication of MZC, the fitness between crown and abutment at the marginal area was confirmed to less than 50 μm by microscopic observation.

*Luting of TZP crown on abutment*

Each sintered MZC was luted to its corresponding metal abutment using either glass ionomer cement (Adshield GI, Kuraray Noritake Dental, Tokyo, Japan) or primer-requiring composite-type resin cement (Panavia V5, Kuraray Noritake Dental). Before luting, abutment and inner wall of MZC were cleansed with ethanol, sandblasted (Jetblast, Morita, Tokyo, Japan) with 50 μm alumina powder at a pressure of 0.3 MPa, and ultrasonically washed.

For the glass ionomer cement group, cement was applied on the inner walls of MZC and set on the...
abutment; then a constant load tester was used to apply a force of 150 N for 3 min. After removal of residual cement, specimens were placed in 37°C thermostatic chamber for 1 h based on the JIS T 6607 \(^{(15)}\) and JIS T 6611 \(^{(16)}\). Thereafter, specimens were taken out of the chamber and placed in 37°C distilled water for a period of 24 h; calculated from time of cement mixing.

For the resin cement specimens, functional monomer with phosphoric ether group (MDP)-containing ceramic primer (Clearfil® Ceramic Primer Plus, Kuraray Noritake Dental) was applied on inners walls of MZC, and MDP-containing metal adhesive primer (Panavia V5 Tooth Primer, Kuraray Noritake Dental) was applied on abutment for 20 s and air dried with oil-free air. Resin cement was applied inside the crown wall and set on the abutment; then a constant load tester was used to apply a force of 150 N for 3 min. After removal of residual cement, oxyguard (Oxyguard II, Kuraray Noritake Dental) was applied on margins and specimens were placed in 37°C thermostatic chamber for 1 h. Thereafter, specimens were taken out of the chamber and placed in 37°C distilled water for a period of 24 h; calculated from time of cement mixing.

**Static fracture load test**

Static fracture load test was performed using a universal testing machine (Autograph AG-I 20 kN, Shimadzu, Kyoto, Japan). A jig (Tokyo Giken, Tokyo, Japan) was used to mount the abutment so that the indenter was parallel on the testing machine in the axial direction. The indenter had a diameter of 9.0 mm with a semi-cylindrical shape. Before fracture loading test, articulation paper (ARTICULATING PAPER, GC, Tokyo, Japan) and registration strips (Occlusal Registration Strips, Artus, Englewood, NJ, USA) were used to check the load position and contact state. Axial loading was applied at a crosshead speed of 1.0 mm/min until fracture. Fracture load was established as the maximum load.

**Classification of fracture location**

Fractured MZC were observed under a stereomicroscope (VH5000, Keyence, Osaka, Japan) and classified accordingly. For MZC of groove-type abutments, distance from the central fissure to the fracture region on the abutment surface were measured. Fracture regions were divided into 3 areas (Fig. 3):

- **Area I**: Fracture near the central fissure (within 1/3 of the distance between central fissure and groove abyss)
- **Area II**: Fracture before the groove abyss (between 1/3 to 2/3 of the distance between central fissure and groove abyss)
- **Area III**: Fracture near the groove abyss (beyond 2/3 of distance between the central fissure and groove abyss)

Classification of fracture region was defined as the area with fracture-endpoints on the abutment surface.

For MZC of flat-type abutment, fracture regions were classified using the area classification for groove-type abutments as a reference.

Fracture surfaces of some specimens were examined under a field emission-type scanning electron microscope.
Fig. 4 Fracture load of MZC when luted with glass ionomer cement. Same letters indicate no significant difference \((p<0.01)\). W/: groove-type, W/O: flat-type

Table 1 Result of two-way ANOVA for fracture load of MZC luted with glass-ionomer cement

| Source     | Sum of squares | dF | Mean square | F value  | \( p \) value |
|------------|----------------|----|-------------|----------|--------------|
| A: Groove  | 6,446,126      | 1  | 6,446,126   | 39.820   | 0.000        |
| B: Thickness | 22,903,326    | 2  | 11,451,663  | 70.741   | 0.000        |
| Interaction A*B | 399,377      | 2  | 199,688     | 1.234    | 0.309        |
| Error      | 3,885,133      | 24 | 161,880     |          |              |
| Total      | 33,633,963     | 29 |             |          |              |

Fig. 5 Fracture location of MZC luted with glass ionomer cement. W/: groove-type, W/O: flat-type

Statistical analysis
MZC fracture load was statistically analyzed with 2 parameters (preparation type and crown thickness) using two-way ANOVA and Tukey-Kramer multiple comparison tests. Statistical significance was set at \( \alpha=0.05 \).

RESULTS
Fracture load of MZC luted with glass ionomer cement is shown in Fig. 4 and results to two-way ANOVA is presented in Table 1. Fracture load showed significant differences in the two factors (groove and thickness) \((p<0.01)\); however no interaction was indicated \((p=0.309)\). Groove-type abutment group with occlusal crown thickness of 0.3 mm at the central fissure had the smallest fracture load at \( \text{ca. } 3,300\) N. The flat-type abutment group with occlusal crown thickness of 0.7 mm had the highest fracture load at 6,400 N.

Fracture location of MZC luted with glass ionomer cement is shown in Fig. 5. Some specimens completely fractured and fell off the abutment; for these specimens, the larger fragment was used to measure the distance from the central groove to fracture location. Most fractures were seen in Area I regardless of groove or occlusal crown thickness.

Fracture load of MZC luted with resin cement is shown in Fig. 6 and results to two-way ANOVA is presented in Table 2. Fracture load was significantly different in 2 of the main factors (groove and thickness) \((p<0.01)\); however no interaction was indicated \((p=0.498)\). When fracture load was compared, load of groove-type group was slightly lower at all crown thicknesses. Fracture load increased with increasing occlusal crown thickness.

Fracture location of MZC luted with resin cement is shown in Fig. 7. All specimens showed 2 or more fragments after fracture of which one piece always remained on the abutment. MZC of flat-type abutments demonstrated most fractures in Area I. Groove addition...
Fig. 6 Fracture load of MZC when luted with resin cement. 
Same letters indicate no significant difference ($p<0.01$). W/: groove-type, W/O: flat-type

Fig. 7 Fracture location of MZC luted with resin cement. W/: groove-type, W/O: flat-type

Table 2 Result of two-way ANOVA for fracture load of MZC luted with resin cement

| Source      | Sum of squares | dF | Mean square | F value | $p$ value |
|-------------|---------------|----|-------------|---------|-----------|
| A: Groove   | 4,392,645     | 1  | 4,392,645   | 11.010  | 0.003     |
| B: Thickness| 17,078,381    | 2  | 8,539,190   | 21.403  | 0.000     |
| Interaction A*B | 572,283    | 2  | 286,141     | 0.717   | 0.498     |
| Error       | 9,575,234     | 24 | 398,968     |         |           |
| Total       | 31,618,545    | 29 |             |         |           |

and increase in groove depth shifted the fracture location from Area I to Area III. For groove-type with occlusal crown thickness of 0.7 mm, all specimens fractured in Area III.

Figure 8 shows specimens that fractured near the central groove (Fig. 8(a)) and away from the central groove (Fig. 8(b)). The starting points of fracture were unclear in both cases however; flat fractured surface was observed in Fig. 8(a), whereas cleavage fracture, or split crystal planes as indicated by arrow, was observed in Fig. 8(b).
DISCUSSION

This study used standardized metal abutments instead of natural teeth. Dental TZP is known to have higher bending strength and fracture toughness compared to conventional ceramics\(^\text{17}\). Studies have reported that MZC could withstand up to a fracture load of 10 kN when occlusal crown thickness was 1.5 mm\(^\text{10,19}\); however, fracture occurred on the abutment when natural teeth were used\(^\text{13,18}\). This study aimed to find the maximum fracture load of MZC; therefore metal abutments were used to avoid abutment fracture.

Stainless steel (SUS303), used for metal abutments, has an elastic modulus of 193 GPa which is greater than natural teeth (50–80 GPa). Reports indicate that the elastic modulus of the abutment substructure had effects on the fracture load of crowns\(^\text{19,21}\); however, others have reported that abutment stiffness had no effect on fracture load\(^\text{22,23}\). This implies that in order to calculate the fracture load of an abutment, a fundamental relation must be designed where the load does not apply stress on the abutment. Consequently, a stainless steel indenter of a substantial size was used where the stress generated from load did not strain the abutment. Crowns are usually designed so that occlusal contacts are balanced and concentrated stress is avoided. The compromised geometry of the posterior molars tends to often decrease material thickness, especially in the central region, where stress also concentrates\(^\text{24,25}\). In this study, in order to simplify the process of stress generation, a simple crown model was designed with 2 cusps where stress concentration occurred in the central fissure.

V-shape or occlusal grooves on abutment are effective for increasing crown retention\(^\text{3})).\) The V-shape provides greater crown retention than the groove, however the V-shape of abutment tooth requires more tooth preparation than grooves. The groove form ensures clearance in the central pit region while maintaining axial wall height, increasing bonding area for improved retention; and decreasing overall tooth reduction. Adequate height of axial walls promotes crown retention\(^\text{3,8}\). Thus occlusal groove on abutments are conjectured to be appropriate during tooth preparation in clinical settings.

The fracture load of MZC increased with increasing occlusal crown thickness in the central fissure region regardless of groove or cement type. Occlusal crown thickness of 0.3 mm luted with glass ionomer cement had the lowest fracture load at ca. 3,300 N. ACR with porcelain veneering requires at least 1.5 mm of crown thickness in order to withstand a fracture load of 1,000 N\(^\text{20}\). This study suggested that, although the required crown thickness of MZC is 0.5 mm, 0.3 mm crown thickness at the central ridge region is acceptable, even for use in posterior crowns, regardless of groove or cement type.

Our study indicated that an increase in crown thickness of 0.2 mm leads to an increase of 500 N in fracture load. These results are consistent with another study which reported that even for patients with high occlusal forces, a small increase in occlusal crown thickness of MZC will contribute to a substantial increase in fracture resistance\(^\text{6}\). Thus material thickness at the thinnest region of the crown had a significant influence on the fracture strength of MZC.

In this study, the addition of groove decreased the fracture load of MZC. Location of fracture for groove-type specimens was not at the central ridge region, where material thickness was thin, but more along the central ridge to the end of the groove. This tendency was seen only in the resin cement bonded group and the shift occurred further along the end of the groove as groove depth increased. All specimens using resin cement for groove-type with occlusal thickness of 0.7 mm were fractured in Area III. One possible explanation of this reason is that the stress concentration was occurred at the groove edge as the fulcrum, because the thickness of the crown at the edge of occlusal groove and center of groove was almost same for 0.7mm-thick crown. SEM images indicated homogeneous stress distribution occurred on the fracture surface in the specimens which was fractured in Area I. However, more complicated or heterogeneous stress distribution occurred on the surface of the specimens in Area III causing cleavage fracture. Past studies have indicated that simple flat-type occlusal preparation design are preferred in terms of mechanical behavior\(^\text{27})\). Groove addition most likely complicated the stress loaded on the specimen which lead to unbalanced stress within the material and overall reduced fracture strength.

Fracture load in resin cement group was 1.3 times higher than glass ionomer cement group. Groove addition slightly lowered fracture load in the resin cement group, but significantly lowered fracture load in the glass ionomer cement group. For resin cement group, MZC bonding surface was treated with a functional monomer (MDP) containing primer. MDP has shown to improve bond strength of TZP to adhesive resin cements\(^\text{27,30}\). ACR have demonstrated to have increased fracture strength when luted with resin cements. On the contrary, glass ionomer cements exhibit no durable bond with TZP\(^\text{27,31}\). Cohesive fracture of resin cement was seen on abutment and MZC, whereas glass ionomer cement group showed fracture mode commonly seen on brittle materials. Preliminary experiment indicated that resin cement and glass ionomer cement had compressive strengths of 220 and 95 MPa respectively; therefore, the difference in fracture strength may be due to the difference in compressive strength. Resin cement and MZC was strongly bond which lead to significantly higher fracture strength.

This study investigated the fracture load of MZC through static fracture testing. Dental ceramics are brittle and microcracks occur due to fatigue which reduces fracture strength. In addition, TZP undergoes low-temperature degradation, caused by hydrolysis in the oral cavity, which decreases fracture strength. The adhesive bond strength of resin cements to TZP is also reported to decrease after thermocycling\(^\text{27}\). Therefore, in
order to clarify the fracture strength of MZC, accelerated degradation test with continuous load and thermocycling with occlusal condition is required.

Conventional ACR tooth preparation requires greater than 1.5 mm crown thickness for the prosthesis to withstand occlusal forces; therefore excessive tooth reduction was required. In addition, crown retention is dependant on abutment height and adhesion. In this study, 0.3 mm crown thickness at the central pit presented sufficient strength to withstand occlusal forces. This data was derived from glass ionomer cement luted specimens, which was unexpected. Our data also demonstrated that 0.3 mm crown thickness is acceptable for use even in the posterior molar region regardless of cement type so long as the abutment height is sufficient. Subsequently, MZC are appropriate for parafunctional patients with excessive occlusal force, because a slight increase in crown thickness leads to a large increase in fracture strength.

Fracture load decreased with the addition of groove, however the degree of decrease in fracture load was smaller when resin cement was used. When deeper groove was added, fracture occurred near the groove abyss. For this reason, it was suggested that edge form and ridge application on the inner slopes of the central fissure, may contribute to crown thickness and resulting fracture strength of the restoration.

In addition to cutback in tooth reduction, sufficient abutment height and large increase in retention strength can be expected with the addition of groove. In difficult cases where abutment tooth lacks height during preparation for monolithic zirconia restoration, the addition of occlusal groove on abutment and usage of resin cement for luting is effective.

**CONCLUSIONS**

In the present study, the following conclusions were obtained.

1. Addition of groove decreased fracture load of MZC; however the degree of decrease in fracture load was smaller when resin cement was used.
2. The fracture load of MZC increased with the increase of the occlusal crown thickness in the central fissure region regardless of groove or cements.
3. Luting MZC with resin cement increased fracture load by integrating the restoration and abutment.
4. Luting MZC with glass ionomer cement indicated lower fracture load than when luted with resin cement; however the fracture load of MZC is large enough to endure occlusal force.

**REFERENCES**

1) Heintze SH, Rousson V. Survival of zirconia and metal supported fixed dental prostheses: A systematic review. Int J Prosthodont 2010; 23: 493-502.
2) Matsuzaki F, Sekine H, Honna S, Takanashi T, Furuya K, Yajima Y, Yoshinari M. Translucency and flexural strength of monolithic translucent zirconia and porcelain-layered zirconia. Dent Mater J 2015; 34: 910-917.
3) Nakamura K, Harada A, Inagaki R, Kanno T, Niwano Y, Milleding P, Ortgren U. Fracture resistance of monolithic zirconia molar crowns with reduced thickness. Acta Odontol Scand 2013; 71: 602-608.
4) Jang GW, Kim HS, Cho IC, MK Son. Fracture strength and mechanism of dental ceramic crown with zirconia thickness. Proc Dent 2014; 92: 207-212.
5) Shahraf S, van Noort R, Mizakouchaki B, Phasmeieh E, Martin N. Fracture strength of machined ceramic crowns as a function of tooth preparation design and the elastic modulus of the cement. Dent Mater 2014; 30: 234-241.
6) Wiskott HW, Nicholls JI, Belser US. The effect of tooth preparation height and diameter on the resilience of crowns to fatigue loading. Int Prosthodont J 1997; 10: 207-215.
7) Shahraf S, van Noort R, Mizakouchaki B. Effect of the crown design and interface lute parameters on the stress state of a machined crown tooth system a finite element analysis. Dent Mater 2013; 29: 123-131.
8) Burke FJ, Fleming GJ, Nathanson D, Mrquis PM. Are adhesive technologies needed to support ceramics? An assessment of the current evidence. J Adhes Dent 2001; 4: 7-22.
9) Blatz MB, Chiche G, Holst S, Sadan A. Influence of surface treatment and simulated aging on bond strengths of luting agents to zirconia. Quintessence Int 2007; 38: 745-753.
10) Ernst CP, Cohnen U, Stender E, Willershausen B. In vitro retentive strength of zirconium oxide ceramic crowns using different luting agents. J Prosthodont 2005; 93: 551-558.
11) Rosenbitt M, Behr M, Thaller C, Rudeh L, Feilzer A. Fracture performance of computer-aided manufactured zirconia and alloy crowns. Quintessence Int 2009; 40: 655-662.
12) Beuer F, Stimmlemayr M, Gernet W, Edelhoff D, Guh JF, Naumann M. Prospective study of zirconia-based restorations: 3-year clinical results. Quintessence Int 2010; 41: 631-637.
13) JIS T 6607: 1993. Dental glass polyalkenoate cement.
14) JIS T 6611: 2009. Dental resin cement.
15) Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res 2013; 57: 238-261.
16) Strub JR, Beschmidt SM. Fracture strength of 5 different all-ceramic crown systems. Int J Prosthodont 1998; 11: 602-609.
17) Beuer F, Stimmlemayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater 2012; 28: 449-456.
18) Scherrer SS, de Rijk WG. The effect of crown length on the fracture resistance of posterior porcelain and glass-ceramic crowns. Int J Prosthodont 1992; 5: 550-557.
19) Bindl A, Höthby H, Mörmann WH. Strength and fracture pattern of monolithic CAD/CAM-generated posterior crowns. Dent Mater 2006; 22: 29-36.
20) Schmitter M, Mueller D, Rues S. Chipping behavior of all-ceramic crowns with zirconia framework and CAD/CAM manufactured veneer. J Dent 2012; 40: 154-162.
21) Okabayashi S, Nomoto S, Sato T, Miho O. Influence of proximal supportive design of zirconia framework on fracture load of veneering porcelain. Dent Mater J 2013; 32: 572-577.
22) Rekow D, Thompson VP. Engineering long-term clinical success of advanced ceramic prostheses. J Mater Sci Mater Med 2007; 18: 47-56.
23) Dejak B, Motkowski A, Langot C. Three-dimensional finite
element analysis of molars with thin-walled prosthetic crowns made of various materials. Dent Mater 2012; 28: 433-441.

26) Beuer F, Aggstaller H, Edelhoff D, Gernet W. Effect of preparation design on the fracture resistance of zirconia crown copings. Dent Mater J 2008; 27: 362-367.

27) Özcan M, Bernasconi M. Adhesion to zirconia used for dental restorations: a systematic review and meta-analysis. J Adhes Dent 2015; 17: 7-26.

28) Oba Y, Koizumi H, Nakayama D, Ishii T, Akazawa N, Matsumura H. Effect of silane and phosphate primers on the adhesive performance of a tri-n-butylborane initiated luting agent bonded to zirconia. Dent Mater J 2014; 33: 226-232.

29) Tashkandi E. Effect of surface treatment on the micro-shear bond strength to zirconia. Saudi Dent J 2009; 21: 113-116.

30) Sciasci P, Abi-Rached FO, Adabo GL, Baldissara P, Fonseca RG. Effect of surface treatments on the shear bond strength of luting cements to YTZP ceramic. J Prosthet Dent 2015; 113: 212-219.

31) Piwowarczyk A, Lauer HC, Sorensen JA. The shear bond strength between luting cements and zirconia ceramics after two pre-treatments. Oper Dent 2005; 30: 382-388.