Clinical and Experimental Health Sciences

Effect of Cementation and Thermomechanical Aging on the Marginal Adaptation of Veneered and Monolithic Zirconia

Riyad Derviş[1], Ceren Küçük[2], Rim Temizkan Nizaroglu[2], Rifat Gözneli[2]

[1] Marmara University, Institute of Health Sciences, Department of Prosthodontics, İstanbul, Türkiye.

[2] Marmara University, Faculty of Dentistry, Department of Prosthodontics, İstanbul, Türkiye.

Correspondence Author: Ceren Küçük

E-mail: ceren.kucuk@marmara.edu.tr

Received: 20.11.2023 **Accepted:** 08.07.2024

ABSTRACT

Objective: The objective of current study was to evaluate the marginal discrepancy of a manually veneered CAD/CAM zirconia and two different monolithic CAD/CAM zirconia all-ceramic crowns; before and after cementation; before and after artificial aging by using a chewing simulator.

Methods: A total of 36 specimens were divided into 3 groups (n=12) and crown restorations were fabricated by using 3 different type of zirconia materials for each group: Group MZ1: monolithic zirconia crowns (GC initial), Group MZ2: monolithic zirconia crowns (InCoris TZI), Group BZ: bilayered zirconia crowns; zirconia core (InCoris ZI) veneered with a low-fusing glass-ceramic. The specimens were duplicated using epoxy resin before and after cementation and after thermo-mechanical fatigue. The marginal adaptations of replicated specimens were evaluated at six points. The margins were evaluated under a scanning electron microscope. Statistical analysis was performed using SPSS. Tukey HSD test were used to investigate the differences between the three types of zirconia crown restorations. Statistically significant difference was determined at ($p< .05$).

Results: There is a statistically significant difference between specimens before and after cementation, and as well after thermos-mechanical fatigue for the three zirconia materials.

Conclusion: The cementation process showed a significant effect on the marginal gap size in all groups. Additionally, thermo-mechanical fatigue significantly increased the marginal gap in all groups.

Keywords: Marginal fit, monolithic zirconia crown, thermomechanical fatigue.

1. INTRODUCTION

Due to increasing demands for aesthetics, metal-free ceramic restorations have been widely used in the last few years (1,2). The use of tetragonal zirconia polycrystalline which is stabilized by yttria (Y-TZP) for the manufacture of all ceramic frameworks using CAD/CAM technology is common nowadays owing to its exceptional biocompatibility, minimal plaque accumulation, and superior mechanical properties (3,4). Since zirconia has an opaque nature, the desired aesthetics can be achieved by veneering it with more translucent feldspathic porcelain (5).

Previous research has indicated that porcelain veneering and firing may have an adverse effect on the marginal integrity of zirconia-based restorations. (4,6,7).

The fitting accuracy of a full restoration may be influenced by the veneering process due to thermal distortions of the core (8). Castellani et al (9) observed significant defects in the marginal area due to the veneering process in single crowns produced using various all-ceramic systems. The all-ceramic crowns that were investigated showed higher sensitivity to repeated porcelain firing cycles compared to metal ceramic restorations. The veneering process may result in discrepancies in the marginal area, which could contribute to a gap between the restorations and the prepared teeth. (10).

The improvement of zirconia's translucency has been achieved through a reduction in the quantity of light scattering

ISSN:2459-1459

DOI: 10.33808/clinexphealthsci.1392423

sources, such as alumina particles, while maintaining its mechanical characteristics at the same level. Therefore, monolithic zirconia restorations, which are anatomically shaped, were subsequently introduced (11).

With the development of high-translucency zirconia, the production of monolithic zirconia crowns has become possible without the necessity of porcelain veneering. This eliminates potential complications such as porcelain chipping and discrepancies in marginal gaps. Furthermore, monolithic zirconia systems exhibit improved mechanical and aesthetic properties (12,13).

Long term clinical success of dental restorations is affected by fracture resistance, esthetic quality and marginal fit (14). The achievement of optimal marginal fit is an essential factor that significantly influences the success and longevity of dental restorations. Inadequate marginal fit of dental restorations has been found to play a role in the accumulation of plaque and an increased risk of microleakage. These unfavorable conditions might eventually lead to the development of secondary dental caries, pulpal lesions, periodontal disease, and bone loss (15,16).

The marginal gap between 100 and 120 µm has been used as a clinically acceptable range according to the study by McLean and von Fraunhofer (17). The main factors that influence marginal fit are: tooth preparation design, cement space parameters and veneering process (18). The precision of fit may be influenced by variables among different CAD-CAM applications of production, such as: the level of scanning accuracy, the effectiveness of CAD software, the state of zirconia during milling, and the grinding protocol employed by the CAD-CAM system. Furthermore, it has been demonstrated that the post-milling hand adjustments performed by the dental technicians, make significant contributions towards improving the fit of CAD-CAM restorations (14,19,20).

Cementation may also increase the marginal discrepancies of fixed restorations according to the cement space distance. To obtain the precision of fit, the old studies recommended a cement space between 30-50 µm for resin luting cement (21). However, evidence suggests that the cement space of CAD-CAM zirconia crowns should be set at no smaller than 60 µm for better seating on the abutment with minimal need of manual adaptation (19,20).

When subjected to the conditions in oral cavity, zirconia restorations are directly in contact with moisture and exposed to pH changes, mechanical loads and variations in temperature. All of these factors may cause instability in the tetragonal phase that may lead to aging (18,22). Therefore, the evaluation of the marginal fit accuracy is performed after artificial aging as well, that maintains more accurate results of the long-term stability and outcome of the restorations (7).

The objective of the current study was to evaluate the marginal discrepancy of a bilayered CAD/CAM zirconia and two different monolithic CAD/CAM zirconia all-ceramic crowns; before and after cementation; before and after thermomechanical aging by using a chewing simulator. The null hypothesis was that the marginal discrepancy of bilayered would be affected significantly more than monolithic ones by both the cementation and thermomechanical aging.

2. METHODS

This study was approved by the Clinical Research Ethics Committee of Marmara University Faculty of Dentistry (Date-Number:27.12.2018-2018/253). Thirty-six recently extracted human mandibular molars were selected (n=36) according to the criteria including: being intact, non-carious and having similar dimensions bucco-lingually and mesio-distally. The exclusion criteria were that the teeth had: caries, restorations, anatomical defects and visible fracture lines. All teeth were cleaned by using an ultrasonic scaler and stored in 0.1% thymol solution at room temperature until tooth reduction process. The teeth were mounted in a self-curing acrylic resin (Imicryl SC; Imicryl Dental Materials, Inc, Konya, Turkey) by pouring in a cylindrical PVC mold to make cylindrical acrylic blocks. The teeth were positioned perpendicular to upper surface of acrylic blocks and 1 mm below the cement-enamel junction by using a dental surveyor (Kavo EWL; Kavo Elekrotechnisches Werk GmbH, Leutkirch im Allgau, Germany). Following a standardized tooth preparation protocol, the tooth reduction was made using a diamond rotary instrument with a convergence angle of 60 (Meisinger 880G, Hager & Meisinger, Neuss, Germany) after fixing the high-speed handpiece on the same dental surveyor (Kavo EWL, Germany). The high-speed handpiece was positioned to obtain the diamond bur parallel to the axis of the tooth to obtain approximately 60 convergence angle after reduction (Figure 1). A 1.5 mm circumferential reduction at axial and 1.5-2 mm reduction at occlusal surfaces were performed with a chamfer finish line. All sharp edges and margins were rounded. Impressions of the prepared tooth samples were made by using a putty-wash technique in dental plastic cups. After light-body silicone impression material (Elite HD+; Zhermack Spa, Badia Polesine, Italy) was syringed around the prepared teeth and putty silicone in the plastic cups, the prepared teeth were inserted in the cup by handling from the acrylic blocks. Five hours after removing the impression from the tooth samples, a type IV dental stone (Fujirock EP, GC Europe, Leuven, Belgium) was poured in the impressions. After a setting time of 1 hour, casts were removed from the impressions.

A total of 36 specimens were divided into 3 groups (n=12) and crown restorations were produced by using 3 different type of zirconia materials for each group:

- Group MZ1: monolithic zirconia crowns (GC initial; GC America, Alsip, IL, USA) (n=12)
- Group MZ2: monolithic zirconia crowns (InCoris TZI; Dentsply Sirona, Charlotte, USA) (n=12)
- Group BZ: bilayered zirconia crowns; zirconia core (InCoris ZI; Dentsply Sirona, Charlotte, USA) veneered with a low-fusing glass-ceramic (IPS Emax Ceram; Ivoclar Vivadent AG, Schaan, Liechtenstein) (n=12)

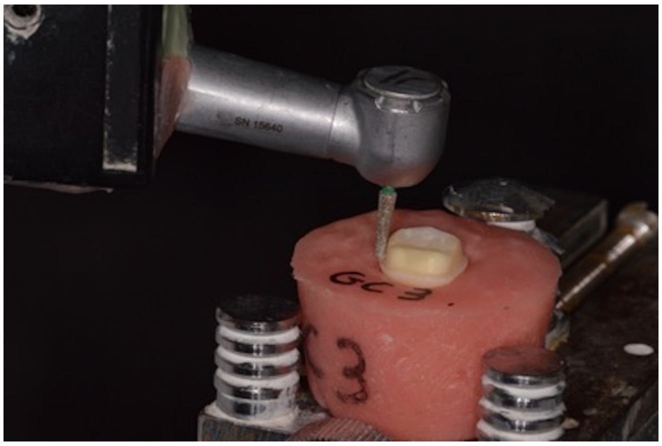

Figure 1. *The position of the high-speed handpiece fixed on the dental surveyor to obtain the reduction with a 6^0convergence angle.*

The casts were scanned and digitized (CEREC inLab; Sirona Dental Systems GmbH, Bensheim, Germany) to fabricate the zirconia crown restorations. The crowns of the first 2 groups (Group MZ1, Group MZ2) and the frameworks of Group BZ were designed and milled by a CAD/CAM unit (CEREC inLab; Sirona Dental Systems). The crowns of Group MZ1 and Group MZ2 were milled from different pre-sintered zirconia discs (respectively; GC Initial; GC America, Alsip, IL, USA; InCoris TZI; Dentsply Sirona, Charlotte, USA) in the milling unit (CEREC inLab; Sirona Dental Systems GmbH) and sintered in a furnace (InFire HTC speed; Sirona Dental Systems). The zirconia frameworks of Group BZ (thickness 0.7 mm) were steam cleaned and veneered with layering porcelain (IPS e.max Ceram; Ivoclar Vivadent AG). The ceramic material performed the firing process in a furnace (Programat S1; Ivoclar Vivadent AG). The manufacture of monolithic restorations (GC Initial; InCoris TZI) were left without ceramic layering and only a glaze layer was applied (Ceram Glaze; Ivoclar Vivadent AG, Schaan, Liechtenstein). A cement space of 60 µm was selected for all crowns during the designing procedure.

The crowns were seated on their relevant abutments and an impression was made for each sample using polyvinyl siloxane impression material (Elite HD+ silicone impression material; Zhermach, Badia Polesine, Italy). Then, the models were obtained by pouring epoxy resin material (Morasin; Moravia, İstanbul, Türkiye) in the impressions. Thus, the replicas of crowns before cementation were prepared for measuring the marginal gaps. To measure the marginal gaps of crown after cementation, all crowns were cemented on their relevant abutments using a self-adhesive resin cement (G-CEM LinkAce; GC America, Alsip, IL, USA). After the resin cement was applied in the crowns, the crowns were cemented with finger pressure and light cured for 20 seconds to all surfaces and margins. The impression was made for cemented crowns and, the epoxy models for crowns after cementation were made as mentioned above. Thus, the replicas of crowns after cementation were prepared for measuring the marginal gaps.

All specimens were artificially aged in a computer-controlled chewing simulator CS-4 (SD Mechatronik). The cemented crowns were submitted to an aging procedure: 2 400 000 cycles, 80 N, at 37°C under artificial saliva bath. The load was applied vertically to the central occlusal fossa of the crowns using a 1.7 Hz steel antagonist ball with a diameter of 6 mm. The test chambers were subjected to a thermal cycling process involving the flooding of deionized water at a temperature of 5°C for a duration of 30 seconds and subsequent flooding with water at a temperature of 55°C for another 30 seconds to result a total of 3000 thermal cycle. After the simulation in the chewing machine the impression made on artificially aged crowns and the epoxy models for crowns were made as mentioned above. Thus, the replicas of crowns after artificial aging were prepared for measuring the marginal gaps.

The replicated specimens were subjected to evaluation of the marginal adaptation for six points: two buccal, two lingual, one mesial and one distal points. The margins were evaluated in entirety under a standard 200x magnification scanning electron microscope (Zeiss EVO LS100 Carl Zeiss AG, Germany) to distinguish the marginal gap between the three groups materials before cementation, after cementation and after thermomechanical fatigue test. The marginal gap interfaces were identified by an expert technician using SEM images (Figure 2).

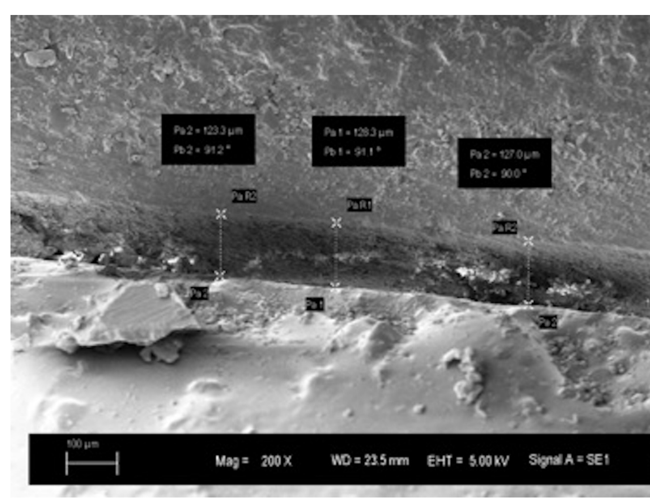

Figure 2. *The measurement of the marginal gaps on 200x magnification SEM images.*

Data was entered and analyzed using SPSS (SPSS 23.00, SPSS Inc., Chicago, IL, USA), descriptive statistics and inferential statistic techniques were used for data analysis. One-way ANOVA test was used to compare between the groups. Repeated measures ANOVA was used to analyze the effect of cementation and aging. Tukey HSD test was used to analyze the differences between the three types of Zirconia. Statistically significant difference was determined at $p < .05$.

3. RESULTS

The mean values and standard deviations (SDs) of the measured vertical marginal gaps at the six measuring points for the three groups are shown in table 1. The lowest marginal gap was recorded in MZ1 group before cementation while the highest marginal gap was recorded in the BZ group after aging. One-way ANOVA test showed no significant difference in the mean marginal gap between the three groups before cementation, after cementation and after aging (p< .05). Repeated measures ANOVA test showed that statistically significant difference found between before cementation, after cementation and after aging in each one of the three groups (p< .001).

Tukey results showed that all groups showed statistically similar marginal gaps before cementation and after cementation while there was statistically significant difference after aging between MZ2 and BZ groups (Table 2).

Table 1. *Mean and standard deviation values of marginal gap before cementation, after cementation and after aging for MZ1, MZ2 and BZ (μm*

Group	Before Cementation	After Cementation	After Aging	p*
MZ1	64.48(13.92)	104.25(8.75)	123.84(10.07)	.000
MZ2	64.71(10.98)	101.71(7.75)	120.68(9.35)	.000
BZ	62.52(10.42)	103.58(9.03)	126.05(11.62)	.000
#p	.660	.602	.306	

**Repeated measures ANOVA test, p= .001*
 # One-way ANOVA Test, p= .05

Table 2. *Paired comparisons between groups*

Groups	Before cementation		After Cementation		After aging	
MZ1	MZ2	BZ	MZ2	BZ	MZ2	BZ
	.993	.582	.177	.884	.165	.410
MZ2	MZ1	BZ	MZ1	BZ	MZ1	BZ
	.993	.511	.177	.390	.165	.006*
BZ	MZ1	MZ2	MZ1	MZ2	MZ1	MZ2
	.582	.511	.884	.390	.410	.006*

According to Tukey HSD test
**The mean difference is significant at the p= .05 level.*

4. DISCUSSION

This study evaluated the marginal fit of 3 different zirconia all-ceramic crowns before cementation, after cementation and after thermomechanical fatigue loading in a masticatory simulator. The null hypothesis, that the marginal discrepancy of bilayered zirconia would be affected significantly more than monolithic ones by both the cementation and thermomechanical aging was accepted.

CAD/CAM zirconia is fabricated mainly by 2 different methods such as: directly digitalization intraorally and indirectly digitalization of the cast produced by an analog impression. It was reported that, although direct digitalization method indicates significantly smaller values for marginal fit in addition to time and material consuming disadvantages of indirect digitalization, the marginal fit for both methods were within the range of clinical acceptance. In current study, indirect digitalization method was used for all group samples' fabrication (20).

In current study, to evaluate the marginal gaps at different fabrication stages between different groups of materials, replica technique was used. This technology takes less time to create specimens and the original abutment tooth can be conserved (7).

Scanning Electron Microscopy (SEM) technique was also used to determine the gap marginal adaptation of crowns fabricated with 3 different zirconia CAD/CAM materials. This method is considered reliable and accurate method for the evaluation of accuracy of dental restorations (23). Some studies in CAD/CAM restorations measure the marginal gap using SEM with different techniques; either directly or from epoxy replicas (24-26). On the other hand, Groten et al (27) reported that the potential of error in SEM is around 10%, making it unsuitable for the assessment of marginal gap. This is mostly due to variances in electron beam strengths in SEM, which result in disparities between black and white graphic regions on the scanned materials. The thermomechanical fatigue and cementation that was applied to the ceramics, proved deterioration in marginal gap, in the current study, thus it could be argued that the SEM is a good predictor of the marginal gaps (28,29).

According to Ferrini et al (30) measurements were taken at the buccal, palatal, mesial, and distal parts of the abutment-coping interface, as well as at intermediate levels of these points for a total of eight readings, which is close to current study. In the current study marginal gap was measured two points from buccal, two points from palatal, one point from mesial and one point from distal surfaces in total 6 readings.

In all experimental groups the mean marginal gap before cementation was between 62.5 μm and 64.4 μm, and after cementation it ranged between 101.7 μm and 104.2 μm. This is considered as a clinically acceptable gap. Guess et al (31) found a mean marginal gap of 30-35 μm before cementation and 49–63 μm after cementation. Other studies also reported that the marginal fit before cementation ranged between 50 to 60 μm (32,33). The marginal fit usually increases significantly after cementation due to numerous factors such as viscosity of the luting agent, filler particle size and preparation design (34). In this study, the finger of the researcher was used to press on the crowns during the cementation procedure. This step was used to simulate the clinical procedure. Att et al (7) also used finger pressure to simulate the clinical procedure but stated that it is considered as a limitation of the study because the pressure of the finger is variable and couldn't be standardized.

The main objective of the study was to determine the difference between before and after cementation and after thermo-mechanical fatigue for each zirconia material. The results presented show a statistically significant difference in nearly all the variables, this accepts the null hypothesis. In all zirconia materials, there was a statistical difference between before and after cementation, a difference between before cementation and after thermo-mechanical fatigue, as well there was a difference between after cementation and after thermo-mechanical fatigue.

The results of this study were consistent with Martinez-Rus et al (35) who evaluated the marginal adaptation between computer-aided design/computer-assisted manufacture lithium disilicate, pressed lithium disilicate and CAD yttrium-stabilized tetragonal zirconia polycrystalline on implant abutments before and after cementation and concluded that marginal discrepancies increased significantly after cementation for all abutment – crown combinations. In addition, Kale et al (13) compared the marginal fit of monolithic zirconia crowns before and after cementation and found that the cementation significantly affected the marginal gaps of CAD-CAM monolithic zirconia crowns.

On the other hand, Gonzalo et al (21) evaluated the marginal fit of 3-unit FPDs manufactured from Lava All-Ceramic System, Procera Bridge Zirconia, VITA In-Ceram before and after cementation and concluded that the marginal gap was increased slightly after cementation in all the groups but the difference was not significant and explained this result that the luting space of 50 µm is enough to obtain adequate space for the cement.

Regarding the thermomechanical aging effect on the marginal gap, several study results were consistent with the results of this study (36-38).

Thermal and mechanical load cycles may generate significant stresses at the interface of the restorations, resulting in the failure of the cement interface. The marginal adaptation might undergo additional degradation due to the varying thermal expansion between the cement and the tooth or restoration, and also because of the repeated application of mastication forces (36,39,40). On the contrary, Del Pinal et al (18) conducted a study comparing the marginal fit before and after thermomechanical fatigue of veneered zirconia and monolithic zirconia crowns and stated that the aging process did not alter the marginal fit of zirconia crowns.

Regarding the differences of the marginal gap between the groups, there was no significant differences between any of the groups before cementation or after cementation. After thermomechanical fatigue, BZ group showed significantly higher mean marginal gap compared to MZ2 group.

Similar to this result, Rayyan (12) compared the marginal fit between porcelain veneered zirconia crowns and high-transluceny monolithic zirconia crowns and concluded that monolithic zirconia crowns showed superior marginal accuracy than porcelain-veneered zirconia crowns. The larger marginal space of veneered copings may be attributed to a number of factors, including the firing shrinkage of veneering porcelain. The porcelain shrinkage produces a compressive force on the frameworks and causes enlargement of the gap (41).

Conversely, Saraswathi et al (42) compared between monolithic zirconia and multilayer zirconia crowns in terms of marginal gaps and found no significant differences. They suggested that the resistance to porcelain firing shrinkage of zirconia copings was a result of their superior strength.

Several limitations were identified in the present study. The use of extracted natural teeth might alter the optimal standardized conditions. Additionally, finger pressure was used during cementation to press on the crowns until the cement was set. These are considered limitations but were performed to simulate the clinical conditions.

5. CONCLUSION

With regard to the limitations of this study, the subsequent results may be derived: All evaluated materials before cementation and after cementation showed clinically accepted mean marginal fit (less than 120). After aging process, all evaluated materials showed mean marginal gap higher than the accepted range. The cementation process showed a significant effect on the marginal gap size in all groups. Additionally, thermo-mechanical fatigue significantly increased the marginal gap in all groups.

Acknowledgements: *This study was supported by the donation of requested materials by GC Türkiye and Dentsply Sirona Türkiye.*

Funding: *The author(s) received no financial support for the research.*

Conflict of interest: *The authors have no financial interest in the companies that donated the materials used in this study and declare no conflict of interest.*

Ethics Committee Approval: *This study was approved by Clinical Research Ethics Committee of Marmara University Faculty of Dentistry (approval date 27.12.2018 and number 27.12.2018-2018/253)*

Peer-review: *Externally peer-reviewed.*

Author Contributions:

Research idea: CK

Design of the study: CK

Acquisition of data for the study: RD

Analysis of data for the study: RD

Interpretation of data for the study: RD, RTN

Drafting the manuscript: RTN

Revising it critically for important intellectual content: RG

Final approval of the version to be published: RG, CK

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How to cite this article: Derviş R, Küçük C, Temizkan Nizaroğlu R, Gözneli R. Effect of Cementation and Thermomechanical Aging on the Marginal Adaptation of Veneered and Monolithic Zirconia. Clin Exp Health Sci 2024; 14: 745-751. DOI: 10.33808/clinexphealthsci.1392423