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Original Paper

Effect of preparation angles on the precision of zirconia crown copings fabricated by CAD/CAM system

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The aim of this *in vitro* study was to evaluate the effects of different preparation angles on the precision of fit of zirconia crown frameworks. Dies were fabricated with three different preparation angles: 4, 8, and 12 degrees total taper. Ten copings were fabricated for each angle by a laboratory and a milling-center CAD/CAM system. After cementation, cross-sections were obtained and cement gaps were measured.

Preparation angle (ANOVA, $p<0.01$) and measurement location (ANOVA, $p<0.01$) exhibited statistically significant influence on the precision of fit. On the other hand, no statistically significant influences were detected between copings prepared using the laboratory and milling-center CAD/CAM systems (ANOVA, $p=0.92$). All groups showed marginal openings ranging between 36.6 and 45.5 μm.

In light of the results obtained in this study, a preparation angle of 12 degrees is hence recommended with the confidence that the marginal gap will be consistently less than 50 μm.

Key words: Preparation angle, Zirconia, Precision

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INTRODUCTION

All-ceramic restorations offer excellent esthetics and have been successfully used for restoring anterior and posterior teeth[1-6]. Similar to the metal-ceramic technique, the construction of zirconia-based restorations uses a high-strength ceramic material for the framework to provide sufficient resistance against cyclic loading. Apart from the mechanical properties and esthetics, another key factor that determines the long-term clinical success of dental restorations is marginal deviation[7-9]. Poor marginal adaptation of restorations increases plaque retention and changes the composition of subgingival microflora, leading to the onset of periodontal disease[10,11].

Microleakage at the restoration-cavity wall interface can cause pulpal inflammation[7,12]. The presence of marginal discrepancies in a restoration exposes the luting agent to the oral environment. The larger the marginal discrepancy and coupled with the subsequent exposure of the dental luting agent to oral fluids, the more rapid will be the rate of cement dissolution[13]. American Dental Association (ADA) Specification No. 8 states that the luting cement film thickness for crown restorations should not be more than 25 μm when using a Type I (fine particle size) luting agent, or 40 μm with a Type II (medium particle size) luting agent[14]. As a clinical goal, it has been suggested that marginal gaps of cemented restorations should range from 25 to 40 μm. However, marginal openings within this range are seldom achieved clinically. On the contrary, a study that clinically examined more than 1,000 crowns after five years of clinical service concluded that marginal openings less than 120 μm were clinically acceptable[15,16].

It has been shown that using milling devices for dense zirconia, high precision can be achieved with marginal openings reportedly ranging between 60 and 74 μm[8,16-18]. If zirconia material is used in a semi-sintered porous state (white blank), it can be easily machined in a computer-aided manufacturing (CAM) unit. After machining, the framework has to be sintered densely[19-21]. Upon sintering, volume changes result from the relocation of the material *via* bulk diffusion, surface diffusion, or the gas phase[21-23]. This may lead to a linear sinter shrinkage of 15-30% and a subsequent increase in density[22,23]. However, the obvious efficiency of this fabrication method is peppered with reasonable doubts as possible inaccuracies may arise from the scanning process, software design, milling, and shrinkage. Clinical studies have shown a mean marginal gap of 65 μm for fixed partial dentures (FPD) fabricated using the Lava system (3M ESPE, Seefeld, Germany), which carries out milling in a semi-sintered state[22].

On the marginal fit of restorations, numerous *in vitro* studies have been carried out using tooth-colored materials fabricated with different preparation angles between 6 and 15 degrees[9,24-26]. In a study[26] that compared the marginal fit and fracture strength of different preparation angles, it was found that decreasing the convergence angle of single crowns reduced the marginal gap and increased the mechanical stability. However, the study[26] was conducted using fiber-reinforced composite crowns, making comparison to zirconia-based restorations questionable. In another study by Tuntiprawon and Wilson[27], it was reported that all-ceramic crowns displayed greater fracture strength when the mean cement thickness at the axial wall was 73.0 μm. However, if cement thickness at the axial wall was increased to 122.0 μm, lower fracture strength was obtained without any significant improvement in seating[27].

In the present study, the CAD/CAM system used offered two options for fabrication: the copings were either fabricated in the dental laboratory (Cercon brain, DeguDent, Hanau, Germany) or at the milling center (Compartis, DeguDent). While the same scanning unit, software, and semi-sintered zirconia were used, different CAM milling machines were used at different fabrication locations. This experimental design sought to address the question if the location of fabrication influences the precision of fit of a prosthesis.

Numerous studies have been undertaken to examine the accuracy of dental restorations[7,8,21-26], but none — to the best of the authors' knowledge — evaluated the effect of preparation angles on the precision of fit of zirconia copings. Against this background, the purpose of this *in vitro* study was to examine the influence of preparation angles on the precision of fit of zirconia-based single crowns. The hypotheses to be tested in this study were: (1) The preparation angle exerts no influence on the precision of fit of zirconia copings; (2) The location of fabrication exerts no influence on the precision of fit of zirconia copings; and (3) All experimental groups will show clinically acceptable marginal openings.

MATERIALS AND METHODS

Coping fabrication

Three acrylic maxillary right molars (Frasaco, Tettnang, Germany) were prepared using different preparation angles: 4, 8, or 12 degrees. A silicon impression (Optosil, Heraeus Kulzer, Hanau, Germany) was made before preparation to control the volume of substance to be removed. Additionally, a provisional crown (Protemp 3 Garant, 3M ESPE, Seefeld, Germany) was used to determine the amount of substance to be removed at the circular and occlusal areas (Dial Caliper, Kori Seiki, Tokyo, Japan). The preparation was finished in a parallel guidance unit (F1, DeguDent) using different carbide finishers (Brasseler, Lemgo, Germany) to ensure that the preparation angles, α, were 4, 8, and 12 degrees. The occlusal surface was reduced by 1.5 mm according to the anatomical shape. Approximate height of each prepared molar was 5.5 mm. All sharp margins were rounded and finished 0.5 mm apical to the cementoenamel junction. Twenty polyether impressions were made (Impregum, 3M ESPE) with a metal impression tray (U3 #141163 Orbilock, Orbis Dental, Munster, Germany) and filled with a Type IV resin-reinforced (ISO Type IV) die stone (Resin Rock, Whip Mix Corp., Dortmund, Germany). The same investigator made all the impressions, and the same experienced technician fabricated all the dies.

Digitalization of the dies was performed using a laser scanner (Cercon Eye, DeguDent) and the copings were designed on the system's CAD program (Cercon Art, DeguDent). Construction of the copings was carried out using a standard protocol, whereby the settings were: 0.4 mm wall thickness and 20 μm of virtual cement layer starting at 1 mm above the margin.

Ten zirconia copings of each preparation angle were fabricated using a laboratory CAM unit (Cercon Brain) at the laboratory of Munich Dental School. Data were enlarged by 30%, and the frameworks were milled from semi-sintered zirconia blanks (Cercon Base 12 mm, DeguDent). The milled, enlarged frameworks were sintered to full density at a temperature of 1350°C, resulting in shrinkage to the desired dimensions.

Similarly, 10 zirconia frameworks for each preparation angle were fabricated at a milling center (Compartis). Data of the designed copings were sent *via* Internet to the milling center and the sintered copings were delivered after 48 hours.

Precision of fit measurement

All frameworks were returned to their respective dies and controlled in terms of seating. In the event of incomplete seating, additional adaptation of the framework was performed using a standard protocol according to published literature and clinical practice[28]. To identify areas that needed correction, a lipstick (Shine Délicieux, L'Oréal, Paris, France) was applied to the master cast and the framework was placed without force. The red spots inside the framework were removed using a red ring diamond ball instrument (Komet 8801.016, Brasseler) with a water-cooling spray. This procedure was repeated until the marked indicator spots disappeared and a uniform and even contact of the coping on the die was achieved. After each refinement, the color was removed from the die using a steam cleaner. The same experienced dental technician adapted and checked all the restorations. After the adaptation process, the supervising dentist controlled the seating. Examiner inter-agreement factor was 95%.

Fit of the copings was measured in this study without veneering, as it is mainly the retainer which determines the overall fit of a veneered restoration[7]. The copings were examined for deformity and debris, and then cleaned with steam (Triton SLA, Bego, Bremen, Germany). All copings were cemented onto their master casts with a glass ionomer cement (KetacCem Aplicap, 3M ESPE). Cement was applied on the copings using an Aplicap Applier (3M ESPE) and then spread out using a disposable brush until the complete surface was coated. The coping was placed on the definitive die with finger pressure, and excess cement was removed. In addition, a special cementing device ensured that a loading force of 50 N was centrally applied on the coping[29] for 10 minutes. An experienced dentist who seated the coping on the die, and a dental assistant who activated the cement capsule and started the mixing procedure, performed the cementation procedure. The midlines of both abutment teeth were marked on the die to the end of achieving comparable sectioning.

At 24 hours after cementation, every framework was embedded in gypsum (Resin Rock, Whip Mix Corp.). The embedded specimens were sectioned centrally with a circular saw (Accutom-2, Struers, Willich, Germany) from buccal side to palatal side and from mesial end to distal end, according to the pencil lines. As a result, four specimens were obtained from each framework for evaluation.

The frameworks were examined at original magnification ×50 (Axioskop 2, Zeiss, Oberkochen, Germany). Four digital images were acquired for each slice. One image of a calibration slide was made at the same magnification and used as a reference for calibration at each imaging session. In addition, two images of the marginal area were made alongside the calibration slide at the same magnification. Photographs were taken with a digital camera (S1 Pro, Fuji, Tokyo, Japan) and transferred to an imaging data program (Optimas 6.5, Media Cybernetics, Silver Spring, USA).

Measurements were made at every 50-μm interval starting at the marginal opening, resulting in 350 measurement points per slice. The measurement was performed using the following method. A series of points were placed on the die and the internal surface of the restoration. These points were placed automatically by a computer program with an operator controlling the procedure. The computer program connected two points on one side, and a perpendicular was dropped from a point on the opposite border. The perpendicular distance was the measured cement gap in micrometers (μm).

For each coping, the following four measurement locations were used to determine the precision of fit between the coping and the die:

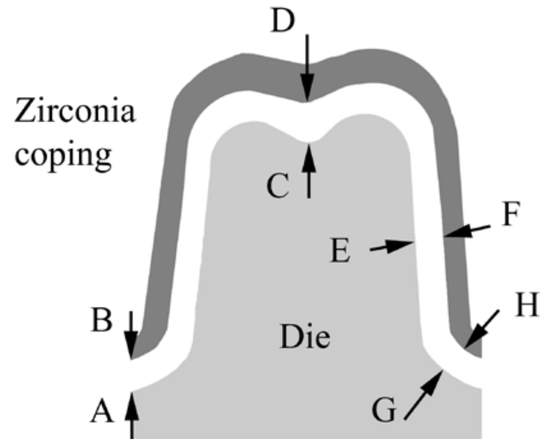

Fig. 1 Crown-to-die diagram showing the measurement locations used to determine the precision of fit at crown-to-die interface. Measurement location CA: points G–H, AW: points E–F, OA: points C–D, MO: points A–B.

1. Chamfer Area (CA): Internal adaptation of the retainer at the point with the biggest diameter.
2. Axial Wall (AW): Internal adaptation of the crown walls at the midpoint of the axial wall (2 mm occlusal to the margin of the die).
3. Occlusal Adaptation (OA): Internal adaptation of the surface of the crown to the die at the midpoint from the facial and proximal ends.
4. Marginal Opening (MO): Marginal opening at the point of closest approximation between the die and porcelain margin of the retainer.

Using the scan line schema (Fig. 1) planned for this study, measurements taken at CA, AW, OA, and MO measurement locations were used to evaluate the fit of all copings. Data recorded at the different sections of each specimen were averaged by the different measurement locations.

Statistical analysis

Precision of fit data were imported into a statistical program (SPSS 15.0, SPSS Inc., Munich, Germany). Mean data were calculated and analyzed statistically with descriptive statistics, and two-way analysis of variance (ANOVA) was used to evaluate the influences of these factors: preparation angle, location of fabrication, and measurement location. For further analysis on the influences of the preparation angle and measurement location, a *post hoc* test (Student-Newman-Keuls) was carried out. As for the influence of preparation angles on marginal opening, it was evaluated separately using one-way ANOVA. Level of significance was set at 5%.

RESULTS

For copings fabricated by the laboratory CAD/CAM-system, the mean (SD) marginal openings were 37.5 (37.0) μm in the 4-degree group, 42.3 (44.4) μm in the 8-degree group, and 36.8 (30.9) μm in the 12-degree group. For copings fabricated by the milling center system, the mean (SD) marginal openings were 45.5 (35.7) μm in the 4-degree group, 36.6 (28.9) μm in the 8-degree group, and 40.3 (37.2) μm in the 12-degree group. Regardless of location of fabrication, the largest cement gaps were found at the measurement location OA, while the smallest gaps at the marginal opening (MO). Table 1 lists the mean values of all the experimental groups, while Fig. 2 shows these values according to location of fabrication.

According to ANOVA, preparation angle ($p<0.001$) and measurement location ($p<0.001$) exerted a statistically significant influence on the measured cement gap between coping and die at 5% significance level (Table 2). On the other hand, precision of fit was not significantly influenced by the location of fabrication (Table 2), and neither was marginal opening by the preparation angle ($p=0.863$; Table 3).

Based on the results given in Table 1, precision of fit shown by the 12-degree group was significantly higher compared to the 4-degree and 8-degree groups. When comparing the measurement locations, Student-Newman-Keuls test indicated significant differences among the four measurement locations.

Table 1 Means and standard deviations of gap dimensions of all experimental groups

Preparation angle	Location of fabrication	Measurement location	Mean cement gap (μm)	Standard deviation
4 degrees	Laboratory	CA	80.1	47.3
4 degrees	Laboratory	AW	74.7	56.8
4 degrees	Laboratory	OA	92.0	43.2
4 degrees	Laboratory	MO	37.6	36.7
4 degrees	Milling-center	CA	78.3	19.3
4 degrees	Milling-center	AW	58.4	32.8
4 degrees	Milling-center	OA	98.8	25.4
4 degrees	Milling-center	MO	45.5	35.7
8 degrees	Laboratory	CA	69.9	35.9
8 degrees	Laboratory	AW	60.3	44.8
8 degrees	Laboratory	OA	106.7	37.5
8 degrees	Laboratory	MO	42.3	44.4
8 degrees	Milling-center	CA	67.0	19.0
8 degrees	Milling-center	AW	66.0	37.8
8 degrees	Milling-center	OA	86.2	22.3
8 degrees	Milling-center	MO	36.6	28.9
12 degrees	Laboratory	CA	62.1	19.1
12 degrees	Laboratory	AW	49.3	24.6
12 degrees	Laboratory	OA	73.6	28.8
12 degrees	Laboratory	MO	36.8	30.9
12 degrees	Milling-center	CA	73.3	16.0
12 degrees	Milling-center	AW	39.7	22.9
12 degrees	Milling-center	OA	92.4	25.7
12 degrees	Milling-center	MO	40.3	37.2

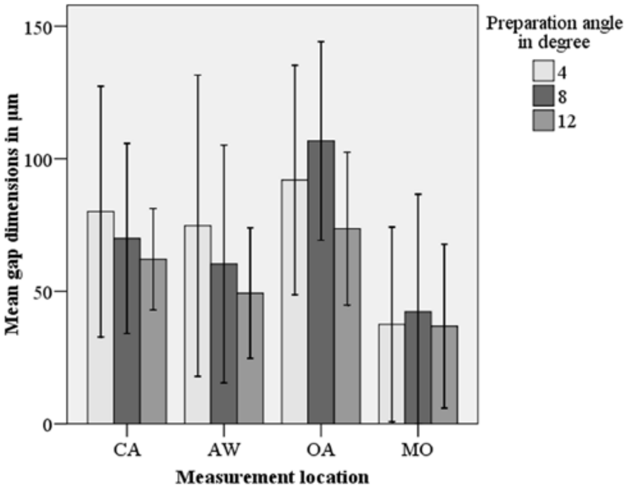

Fig. 2a Means and standard deviations of gap dimensions at four different measurement locations using three experimental preparation angles for the laboratory CAD/CAM-system.

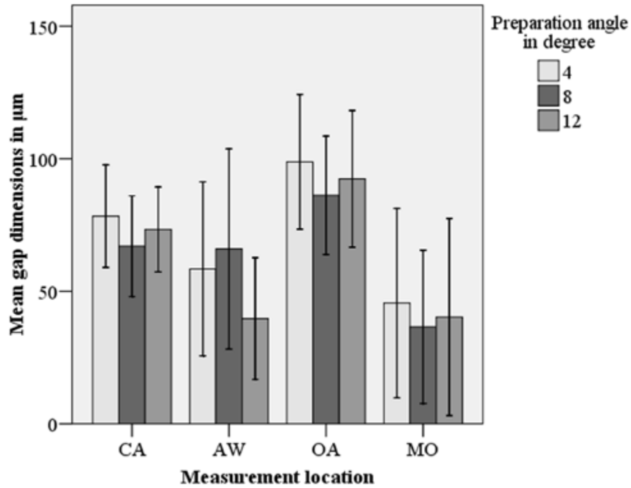

Fig. 2b Means and standard deviations of gap dimensions at four different measurement locations using three experimental preparation angles for the milling center CAD/CAM-system.

Table 2 Two-way ANOVA for preparation angle, measurement location, and location of fabrication

Source	Sum of squares	Degree of freedom	Mean square	F-value	P-value
Preparation angle	24185.853	2	12092.927	10.456	P<0.001*
Measurement location	331486.568	3	110495.52	95.538	P<0.001*
Location of fabrication	11.603	1	11.603	0.010	0.920

*Statistical significance at 5% level

Table 3 One-way ANOVA for preparation angle on marginal fit (MO)

Source	Sum of squares	Degree of freedom	Mean square	F-value	P-value
Preparation angle	379.521	2	189.761	0.147	0.863

DISCUSSION

The preparation angle had a significant influence on precision of fit, thereby squarely rejecting the first hypothesis. It is noteworthy that digitalization might have a certain influence on the overall precision as larger preparation angles allow more data to be obtained from the axial wall. Consequently, this could result in a higher quality of data for the CAM process.

Two other factors may affect the seating of copings: the existence of hydraulic pressure resisting the seating and the removal of excess cement. Hydraulic pressure that is developed during the cementation process is supposed to be higher if the taper of the preparation is lower. In addition, excess cement discharges better if the taper is higher. However, incomplete seating caused by cementation can be excluded in this study as the marginal openings of the experimental groups were not significantly different.

An interesting question that we sought to address in this study was: were the differences in precision significant clinically? The largest cement gaps were found at measurement location OA, a finding well supported by other published studies[12,18,22] and which had a bearing clinically. This is because if too much space were lost as a result of large interocclusal discrepancies, the intercuspal clearance available for veneering would be reduced. Nonetheless, results of the present study indicated that the gaps were similar to or better than those of metal-ceramic restorations[30,31].

From a mechanical strength viewpoint, the cement space or internal adaptation is supposedly a uniform space that facilitates seating without compromising retention and resistance. This is of paramount importance because all-ceramic restorations are more fragile compared to metal-ceramic restorations, as ceramic is a brittle material and sensitive against tension. Therefore, the precision of fit can influence clinical prognosis. Tuntiprawon and Wilson reported that all-ceramic crowns displayed greater fracture strength when the mean cement thickness at axial wall (AW) was 73.0 μm[27]. Their study also showed that when mean AW was increased to 122.0 μm, it resulted in lower fracture strength without any significant improvement in seating[27]. In this study, the experimental groups yielded cement gaps less than or equal to those obtained in other studies in relation to optimal all-ceramic crown strength. Besides, the obtained data did not indicate that there were incidences of axial wall contact between the dies and the retainers, which would have been visible in the cross-sections.

The comparison of milling center CAD/CAM system and small laboratory CAD/CAM system is important for dental technicians and clinicians. Results of this study showed that if the same scanning unit, software, and semi-sintered zirconia blanks were used in the fabrication of zirconia-based crown copings, then the milling device seemed to be of lesser importance as it had no measurable influence on the precision of fit. Therefore, these findings supported the second hypothesis of this study.

An acceptable MO for full crowns, as reported by Hung *et al*., is 50 to 75 μm[32], whereas Weaver *et al.* suggested 70±10 μm[33]. In the present study, the mean MO values for all the experimental groups ranged between 36.6 and 45.5 μm. Therefore, these results supported the third hypothesis of this study concerning marginal fit. When compared to published studies, the marginal opening values obtained in this study were in the same range as CAD/CAM-fabricated alumina crowns, where the latter showed values ranging between 17 μm[12] and 56 μm[24]. For copings fabricated of densely sintered zirconia and at a preparation angle of 6 degrees, smaller marginal gaps of 23 to 33 μm[12] were obtained. However, the copings were adapted before cementation in this study, thereby accounting for the difference in marginal opening results. This suggested explanation thus highlighted the unavoidable impact of human factors on precision of fit, as adaptation is performed by dental technicians in the clinical working procedure. In the same breath, this involvement of human factors also makes comparison of studies difficult. In this study, adaptation was carried out according to a standard protocol and supervised by a second investigator. Nonetheless, all the obtained marginal opening values were within the range defined as clinically acceptable by the authors, thereby proving the reproducibility of the described protocol.

Results of this study also showed that the evaluated CAD/CAM system could successfully calculate the sintering shrinkage of semi-sintered zirconia blanks. The use of semi-sintered blanks offers the advantage of an easy machining process. The block can be machined with a hard metal bur without water cooling or lubrication. As an alternative to the semi-sintered blank technique, zirconia can be machined from a densely sintered blank at a higher cost in terms of material and time.

In addition, results of the present study demonstrated the precision of CAD/CAM systems in laboratory environment. A clinical evaluation of the Lava system reported a mean MO of 80±50 μm, taking into account the inaccuracies caused by the CAD/CAM system and the clinical procedure[22]. An *in vivo* evaluation of alumina crowns showed gap widths that were 61-70 μm wider in bucco-lingual direction and 58-73 μm wider in proximal locations than gap widths measured *in vitro*[34]. It could thus be supposed that marginal openings under clinical environment will be larger as a result of clinical and laboratory inaccuracies.

CONCLUSIONS

Within the limitations of this study, it was concluded that a preparation angle of 12 degrees achieved the best overall precision of zirconia-based single crowns. However, the preparation angle had no influence on marginal fit. On the influence of the location of fabrication, both the laboratory and milling-center CAD/CAM systems achieved equal precision. On clinical acceptability, the zirconia-based crowns fabricated by the evaluated system one can be prescribed with confidence since the marginal gaps will be consistently less than 50 μm.

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