Original Article

Comparison of Marginal Fit and Fracture Strength of a CAD/CAM Zirconia Crown with Two Preparation Designs

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Abstract

Objectives: The purpose of this in vitro study was to compare the marginal adaptation and fracture resistance of a zirconia-based all-ceramic restoration with two preparation designs.

Materials and Methods: Twenty-four mandibular premolars were randomly divided into two groups (n=12); the conventional group received a peripheral shoulder preparation and the modified group received a buccal shoulder and proximal/lingual chamfer preparation. The marginal fit of the zirconia crowns (Cercon) was evaluated using a stereomicroscope. After cementation, load was applied to the crowns. The mean fracture load and the mean marginal gap for each group were analyzed using t-test (P=0.05).

Results: The mean marginal gap was 71±16μm in the conventional group and 80±10μm in the modified group, with no significant difference (P=0.161). The mean fracture strength was 830±153N for the conventional group and 775±125N for the modified group, with no significant difference (P=0.396). All but one fracture occurred in the veneering ceramic.

Conclusion: Less aggressive preparation of proximal and lingual finish lines for the preservation of tooth structure in all-ceramic restorations does not adversely affect the marginal adaptation or fracture strength of the final restoration.

Keywords: Zirconium Oxide; Computer-Aided Design; Prosthesis Failure; Dental Marginal Adaptation

INTRODUCTION

Preserving the remaining tooth structure is a major concern in restorative dentistry [1]. When full coverage of teeth is indicated, a reduction of dental hard tissue is necessary in order to secure structural durability and restore natural anatomy and esthetics. The amount and geometry of the reduction should also decrease stress and provide the best marginal fit to maximize the restoration's longevity and protect the health of the surrounding tissue [2,3]. Currently, the use of high-strength ceramic material is a common practice, particularly in the esthetic zone. Traditional guidelines for the preparation of all-ceramic materials include circumferential tooth reduction by 1-1.5mm, occlusal reduction by 1.5-2mm and uniform shoulder by 1.2mm
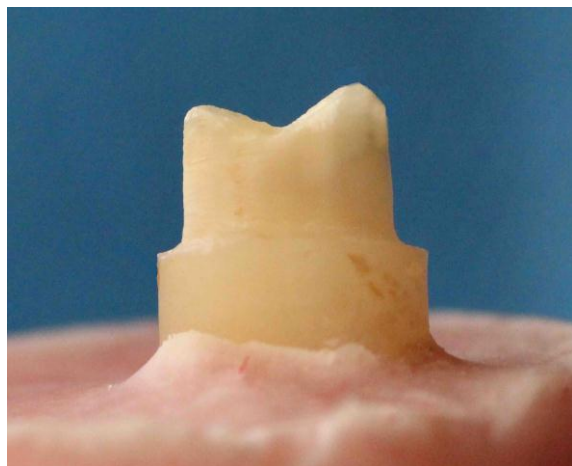
**Fig. 1.** Conventional circumferential round shoulder

in the finish line [4,5]. Observing such guidelines, however, has resulted in a 75% higher reduction of tooth structure [6]. With the advent of tougher ceramics and improved adhesion techniques, chamfer and mini-chamfer finish lines were also suggested [7-9]. Nevertheless, clinical data on how marginal design affects the overall success of zirconia restorations are limited [10].

It is believed that the preparation design may contribute to the durability and fracture strength of final restorations. Research on the effect of marginal design on fracture strength of all-ceramic restorations is based on the premise that functional stress is ultimately transferred to the marginal area and should be borne by sufficient thickness of the ceramic body [7,11]. A larger rest area for margins, such as a shoulder finish line, was suggested to ensure more favorable stress distribution pattern during occlusal loading [12,13]. However, the results of the studies on this subject are not consistent. Some authors found no relationship between the finish line design and fracture strength of all-ceramic crowns [13,14], while significant results were found by others [15].

In practice, all-ceramic crowns are challenging when indicated for small teeth or teeth with a specific morphology, such as mandibular incisors or premolars.

The larger difference in the axial height of contours and cervical periphery endangers those teeth with regard to pulp exposure subsequent to conventional preparation. There is an increasing public demand for replacing existing metal-ceramic restorations with more esthetic restorations. Thus, a modified design is suggested with a narrower finish line in the proximal and lingual areas and a regular round shoulder in the buccal area [16]. This modification, similar to metal-ceramic preparation, may conserve more of the tooth structure and at the same time provide enough ceramic thickness in transition from cervical to occlusal to satisfy gingival health, anatomical morphology and esthetics. Nevertheless, two main concerns may arise. It is evident that non-uniform thickness of ceramic core and/or the veneering ceramic increases the risk of stress concentration and may negatively affect the fracture strength of the restoration [17-19]. In addition, it may affect the marginal fit of the crown due to the fact that the amount of shrinkage is a function of thickness and the difference in the thickness could result in non-uniform distortion and marginal gap [20-24]. Exploring studies on the effect of the finish line on the marginal adaptation of zirconia-based crowns disclosed controversies.

Re et al. reported no significant difference in the marginal adaptation of a heavy chamfer versus a round shoulder in zirconia copings fabricated with one computer-aided design/computer-aided manufacturing (CAD/CAM) system [15]. Euan et al. reported significant effect of marginal design on the adaptation of zirconia crowns, with better results for a 90-degree shoulder rather than a 45-degree chamfer [25]. Three finish lines of shoulder, round shoulder and chamfer did not affect the marginal adaptation of zirconia crowns in a study by Komine et al. [26]. By contrast, Reich et al. showed that a knife-edge preparation resulted in better marginal integrity compared with a chamfer in zirconia copings [12].
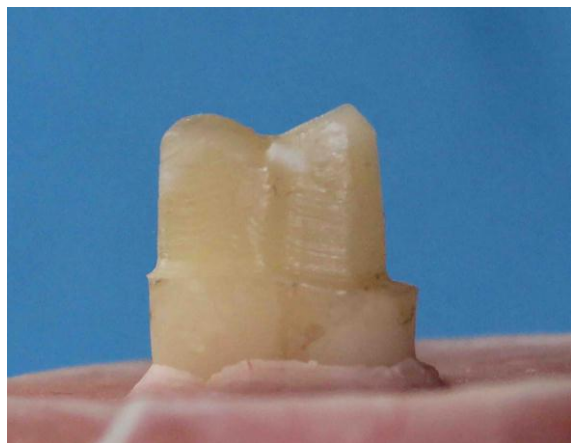
Fig. 2. Modified preparation with buccal shoulder and lingual chamfer

The only study that investigated the combinations of finish lines showed that a combined chamfer-lingual ledge preparation was similar to a chamfer or ledge finish line with regard to the marginal fit of zirconia copings [14]. Therefore, the aim of the present study was to examine the fracture strength and marginal gap of teeth restored with a zirconia-based crown and prepared with the modified design versus a conventional preparation. The null hypothesis tested was that there would be no difference in the marginal gap and fracture strength of zirconia crowns with modified and conventional preparations.

MATERIALS AND METHODS

Twenty-four recently extracted (within the past three months) human mandibular teeth due to periodontal problems were selected for this study. The study protocol was approved in the Clinical Research Ethics Board of Tehran University of Medical Sciences (IR.TUMS 1394.1419). The teeth were cleaned of tissue residues and debris using a hand instrument followed by an ultrasonic scaler (Cavitron, Dentsply, Surrey, UK) and stored in 1% chloramine solution (Halamid, Axcentive SARL, Bouc Bel Air, France) for one week and normal saline until use. Only teeth with no caries, pervious filling, cracks and excessive

wear were included in the study. To ensure similar size, teeth with approximate buccolingual, mesiodistal and occlusocervical dimensions (7.00 ± 0.5mm, 5.00 ± 0.5mm and 5.00 ± 1.00mm, respectively) were included in the study. The teeth were mounted in metal boxes measuring 30mm×30mm×50mm in diameter, with their long axis perpendicular to the surface of the box, with the help of a surveyor (Ney Surveyor, Dentsply Ceramco, York, PA, USA). Each box was filled with autopolymerizing acrylic resin (Major Tray, lot. 06016A, Major Prodotti Dentori S.p.A., Moncalieri, Italy) to 1.0mm below the cementoenamel junction (CEJ). A silicone impression (Elite HD, Heavy Body, lot.74523, Zhermack, Marl, Germany) was made before the preparation of each tooth and used as a guide for sufficient reduction and replication of tooth anatomy during fabrication of the crown restoration. The teeth were randomly assigned to one of two groups (n=12). In group A, the teeth were prepared following conventional guidelines, which included 2mm occlusal reduction, 12° total convergence and 1.2mm circumferential radial shoulder as finish line. The depth of shoulder was controlled by a hand instrument modified to a 1.2mm width. Axial and occlusal reductions were controlled using the putty index. The modified preparation used for group B included 2mm occlusal reduction, total convergence of 12°, buccal shoulder of 1.2mm, and proximal and lingual shoulder 0.8mm in depth using a diamond bur (ISO 856.018, D+Z, Lemgo, Germany) (Figs. 1 and 2). All preparations were finished using a high-speed rotary instrument and a diamond bur (ISO 856.018, D+Z, Lemgo, Germany). A custom impression tray was made for the specimens using autopolymerizing acrylic resin (Major Tray, lot. 06016A, Moncalieri, Italy), and an impression was made using addition silicone material (Regular Body, Lot 95503 Elite; Zhermack, Marl, Germany). All impressions were poured with type IV stone (Fujirock EP, GC Corp., Tokyo, Japan).

Fig. 3. Load application

The stone models were scanned (Cercon Eye Scanner, Cercon, DeguDent, Hanau, Germany) and used for the fabrication of zirconia-based core. A thickness of 30 microns was provided as cement spacer and the final crown was milled out of a semi-sintered block of zirconia (Cercon Base, Cercon, DeguDent, Hanau, Germany) using the scanned digital file as a guide. The patterns were 20-25% larger to compensate for the sintering shrinkage. The milled copings were sintered in a furnace (Cercon Heat, Cercon, DugoDent, Hanau, Germany) to 1450 °C for five hours. Each core coping was tried on the corresponding die (stone model) using disclosing material (Fit checker; GC America Inc., Alsip, IL, USA). Interferences were removed using a diamond bur (ISO 640.015; D+Z, Lemgo, Germany). A coping was discarded if it required adjustment for more than three times. The veneering porcelain was then applied (Cercon Ceramic Kiss, Cercon, DeguDent, Hanau, Germany) after inserting one layer of liner and fired at 970ºC. The dentine porcelain was applied and fired at 830ºC, followed by an enamel layer, which was fired at 820ºC. Final morphology was verified using the putty templates. All crowns were glazed at 800ºC. Marginal adaptation was assessed by measuring the gap between the crown margin and the external surface of the preparation, known as the absolute marginal opening [27,28], before cementation. Three points, in the middle and the most proximal surfaces of buccal, lingual, mesial and distal, were marked using an indelible marker. Crowns were placed and held in place using orthodontic elastic. For each point, three measures were taken and the mean value was recorded. Twelve points were counted for each specimen using a stereomicroscope (Zeiss OPM1; Carl Zeiss, Oberkochen, Germany). All crowns were cemented using dual self-etch resin cement (Panavia F2, lot. 051341, Kuraray Co., Tokyo, Japan) following the manufacturer's instructions. All specimens underwent thermal cycling for 5000 cycles, between 5ºC and 55ºC, with a dwelling time of 15 seconds. After a storage time of seven days in water at room temperature, the specimens were loaded to fracture in a universal testing machine (Zwick Roell Z050, Ulm, Germany) with a semi-spherical stainless steel cross head, 8mm in diameter at a speed of 1mm/min (Fig. 3). This cross head diameter was selected to reproduce cuspal contact [29]. A thin cellulose acetate sheet was placed between the loading head and the occlusal surface of each specimen. It has been suggested that the sheet may prevent accumulation of compressive force at the contact point.

The microleakage data and fracture strength values were verified using Kolmogorov-Smirnov test for normal distribution and Levene's test for homogeneity. Therefore, the mean values of marginal gap between the two groups and the mean values of the fracture loads of the two groups were analyzed by t-test, using statistical software (SPSS 13; SPSS Inc., Chicago, IL, USA) at a significance level of $P<0.05$. The failure mode was assessed under a stereomicroscope (Zeiss OPM1; Carl Zeiss, Oberkochen, Germany).

RESULTS
The minimum marginal gap was found in group A (42.9µm), while the maximum value occurred in group B (95.7µm) (Table 1). Comparison of the mean values indicated no

significant difference in the marginal gaps of the two groups (P=0.161).

The mean fracture load of groups A and B was 830.3±135.5N and 775.7±125.6N, respectively (Table 1). There was no significant difference between the mean fracture loads of the two groups (P=0.40). All fractures occurred at the interface of the veneering ceramic and the core. Out of 24 fractures, 19 occurred in the proximal area of the crowns.

DISCUSSION

In the current study, the marginal fit and fracture strength of the two preparation designs were investigated and no significant differences were found between the marginal adaptations or the fracture strength of the two groups. Therefore, the null hypothesis was accepted. Marginal fit was measured using a stereomicroscope in accordance with previous studies [7,20,24,27]. Although scanning electron microscope has also been recommended in a number of studies, no significant difference was found between the results obtained by these two methods [23]. In addition, stereomicroscopic measurement is a non-destructive and useful method when a fracture test is intended, and extra procedures for producing a replica can be avoided. The marginal discrepancy was measured before cementation, because better optical contrast of the marginal area enhanced reading. Nevertheless, studies evidenced that cementation increased marginal gap [12,19,21,24].

Absolute vertical marginal discrepancy (i.e., the combination of the vertical marginal discrepancy and the horizontal marginal discrepancy), which represents the largest marginal misfit, has been used to evaluate marginal discrepancy in the crowns [28]. It is also the misfit that is measurable clinically in the absence of overextension or under-extension. The crowns were veneered because it has been shown that veneering stages can affect the marginal misfit of the final restorations [21,24]. Thickness of the ceramic material plays a critical role in stress distribution in the final restoration [12,22]. It is believed that thermal history, including the firing cycles and cooling rate during the veneering procedures, can cause residual stresses in restorations. Stress release during cooling is in direct correlation to the volume of the material, and results in restoration misfit [20]. Despite the fact that thermal behavior of core/veneering ceramic is a multifactorial phenomenon, from a clinical point of view, the zirconia framework must be designed in such a way to ensure sufficient veneering thickness within the range of 1-2mm while maintaining the minimum core thickness [19]. In our study, the core thickness was set to 0.5mm, and the veneering thickness was not uniform in order to fabricate the anatomic form of the crown. However, the thickness was not greater than the recommended values. In our study, the absolute marginal discrepancy was not significantly different between the two test groups. In other words, the non-uniform thickness of the veneering ceramic in the margin area in the modified preparation design did not affect the marginal discrepancy compared to the conventional preparation.

Table 1. The mean marginal gap and fracture strength of the test groups

Group	Study groups	Mean (N)	Standard deviation	Standard error of mean
Marginal gap	A	71.59	16.42	5.19
	B	80.68	10.83	3.43
Fracture strength	A	830.30	153.52	48.55
	B	775.70	125.61	39.72

To the knowledge of the authors, there was no similar study to compare our results with. The non-significant results could be explained by the low thermal diffusivity of zirconia crowns, which could dissipate residual stress in the non-uniform veneering layer when the difference in thickness is not large [22]. The mean marginal gap values found in our study were 71.6±16.4μm for the conventional preparation and 80.6±10.8 μm for the modified design, both of which fall within the acceptable range of less than 120 μm [13,27]. Variable values found for the marginal gap of zirconia crowns in several studies ranged from 76.6μm [13], 66.4μm [27], 29.2-74.3μm [8] and 47.0-99.0μm [20]. This wide variability is contributed to several factors, such as type of materials, method of fabrication, test design, and method of marginal gap measurement.

Despite such differences, the results of our study were comparable to data found in the literature, which used the same materials and methodology as we did. For instance, Beuer et al. reported a marginal gap of 82.4±24.6μm for premolar abutment and 80.4±16.3μm for molar abutment when several all-ceramic systems, including Cercon, were examined. Euan et al. found a marginal gap of 76.6±23.0μm for Cercon crowns in their study, and Komine et al. found a marginal gap of 64.0-73.0μm [7,13, 26].

The variable sample size of four to 20, and number of measurements of four to 50 were used in other studies [4,7,21,27]. Since the sample size may affect the insignificant results, a power analysis was performed to estimate the probability of rejecting the false null hypothesis. The power of the study in detecting the difference between the marginal gaps of the two groups with a sample size of 12 was 90.94, which is favorably high.

The fracture strength of crowns between the two groups of the present study did not differ with the mean values of 830.3±153.5N and 775.7±125.6N, for the conventional and modified designs, respectively.

Direct comparison of the results of our study to the literature is not possible due to the absence of similar research. Aboushelib evaluated the effect of three marginal designs including chamfer, circumferential ledge and a combined chamfer and lingual ledge on the fracture strength of zirconia crowns [14]. No significant difference was found in their study. The fracture strength obtained was 746.1±37.0 N for circumferential ledge, 728.9±46.0 N for chamfer and 746.1±37.9 N for the combined chamfer and lingual ledge. The results of this study are close to their values. In a study by Reich et al, [12] the value of 697.0±126.0 N was found for the chamfer and the exceptionally high value of 1110.0±175.0 N was found for the knife-edge design. The difference could be explained by differences in the material used, the preparation design, application of layered ceramic, application of cyclic loading, and the point of fracture measurement.

There are two points of failure during loading of all-ceramic specimens, the point of crack initiation and the final catastrophic fracture, with the higher values recorded for the latter. These two points are not differentiated in some studies. In our study, the crack initiation point was considered as the fracture strength of the specimen.

On the other hand, the mean failure loads in the present study showed no significant difference due to the relatively high standard deviation of the obtained data. High standard deviation is a common finding in the fracture analysis of brittle materials such as ceramics, as a result of random distribution of cracks [18]. In addition, the data obtained from a single static load-to-failure test are a poor estimation of the long-term clinical behavior of all-ceramic restorations. In the clinical setting, restorations are subjected to complex occlusal, functional and parafunctional loads, along with chemical and thermal changes. It was shown that the contact crack zone is not the source of fracture in clinically failed all-ceramic restorations [14].

However, a range of materials or techniques could be ranked in terms of defined variables, such as marginal gap or fracture strength, by in vitro studies in a controlled condition over a far shorter period of time and expense compared with the clinical studies [12,18]. The fracture mode was mostly adhesive at the interface of the veneering porcelain and the core in the proximal area, in particular, where the veneering ceramic received insufficient support from the core. Therefore, the proximal strut (wing), similar to a metal-ceramic coping design, may enhance the fracture of the veneering ceramic in zirconia crowns. This warrants further studies.

CONCLUSION

Within the limitations of the present study, it may be concluded that for small teeth and/or teeth with specific anatomy such as premolars, more conservative preparation of a shallow chamfer in the lingual and shoulder in the buccal has similar marginal fit and fracture strength as teeth with the conventional preparation for zirconia-based crowns.

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