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Effect of Vertical versus Horizontal Preparation on Marginal Accuracy and Fracture Resistance of Monolithic Zirconia Crowns

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Effect of Vertical Versus Horizontal Preparation on Marginal Gap and Fracture Resistance of Monolithic Zirconia Crowns

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Abstract

Purpose: To assess effectiveness of vertical (featheredge) in comparison to horizontal (deep chamfer) preparation on marginal accuracy and resistance to fracture of monolithic zirconia crowns that have been thermomechanically aged. **Patients and methods:** Ten epoxy resin dies were allocated into two equal groups based on the design of the finish line. Group (A): horizontal prep (with 0.7 mm deep chamfer), and group (B): vertical prep (with 0.25 mm featheredge). The epoxy dies were fabricated by duplicating two stainless steel dies, one for each margin design. Then, these epoxy dies were scanned and designed for the milling of monolithic zirconia crowns with two finish line configurations. After being cemented to the epoxy dies, the crowns underwent thermocycling aging. Utilizing a digital microscope, the marginal gap distances were then measured. Following that, the fracture resistance test was conducted using a computer-controlled Universal Testing Machine with a load cell of 5 KN, and data was recorded using computer software. Data was collected and statistical analysis was carried out. **Results:** Featheredge preparation showed statistically insignificant lower marginal gap values than deep chamfer ($P > 0.05$). A statistically significant superior fracture resistance was recorded for the deep chamfer group when compared with the featheredge group ($P < 0.05$). **Conclusion:** Monolithic zirconia crowns with featheredge margins have similar marginal accuracy to those with deep chamfer. Although monolithic zirconia crowns with featheredge margins have lower fracture resistance values, the fracture load values remain within the accepted levels. **Clinical significance:** Vertical preparation for monolithic zirconia crowns can be considered a viable conservative alternative to horizontal preparation.

Keywords: Fracture resistance, Horizontal preparation, Marginal gap, Monolithic zirconia, Vertical preparation

1. Introduction

Generally, two forms of preparation are available: vertical or feather-edge preparation, which lacks a clear finish line, and horizontal preparation, which has a definite finish line [1]. Horizontal preparations, particularly shoulder and chamfer finish lines have been widely used owing to their alleged benefits in preventing overhangs and over-contouring of the restorations, which has also improved workflow and lab-clinician communication.

In certain conditions, such as the presence of periodontally affected abutment teeth for fixed prostheses, vertical preparation was typically recommended since it might be less destructive than horizontal preparation [2]. However, several drawbacks of vertical preparation have been reported in the literature. These included overhanging, disturbance of the biological width, uneven edges, overcontouring, poor esthetics, an inadequate marginal seal, epithelial attachment damage, insufficient tissue healing, and difficulty removing excess cement. Moreover, the thin margins of vertical preparations are difficult to locate by the laboratory technician, and the chipping susceptibility of the restorations has limited the use of such preparation designs [3].

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Because of these drawbacks, horizontal preparation is considered to be the best practice. However, the shift towards a more conservative preparatory method has been increasingly emerging in recent years, nonetheless, as the principal objective of restorative dentistry is achieving good aesthetic outcomes yet still preserving the biological structures [4].

Nowadays, zirconia restorations are widely used because of the increasing need for metal-free restorations [5]. Because it meets both functional and mechanical criteria for fixed prostheses, the material is particularly well-suited for long-term restorations. However, restorations fabricated from zirconia are significantly more opaque than those made of glass-ceramics. To overcome this and improve the esthetics of zirconia prosthetics, ceramic veneering is usually employed [6], but again the most crucial problem with multilayer zirconia prostheses is veneer layer chipping and fractures [7].

Therefore, other solutions were suggested for solving zirconia opacity. By lowering the quantity of alumina particles and other sources of light scattering, zirconia's translucency can be improved without substantially compromising its mechanical properties [8,9]. This resulted in the development of monolithic (anatomically contoured) zirconia restorations that eliminated the need for veneering material. These restorations eliminate the risk of veneer chipping because they are comprised of solely one ceramic substance [10]. Additionally, the construction of monolithic zirconia prostheses is a faster process that saves time and minimizes the technical sensitivity and required effort for its manufacturing [11,12].

When compared with other ceramic restorations, monolithic zirconia requires minimally invasive tooth preparation, thus allowing for prosthetic construction with preservation of a greater amount of tooth structure [13].

Using partially sintered zirconia blanks simplifies the soft milling process and is now the most popular approach for producing zirconia restorations. The milled zirconia prosthetic is subsequently subjected to a specialized sintering process to attain the ultimate density and maximal strength; nevertheless, a significant degree of shrinkage (~20–30%) occurs during the final sintering process. The overall dimensions of the milling framework are enlarged by a predefined proportion to accommodate for such shrinkage [14].

Precise marginal adaptation constitutes one of the essential requirements for the long-lasting success and durability of ceramic prostheses. Due to the ill-fitting margins, a gap can exist between the prepared tooth and the prosthetic restoration, and the greater the gap, the more is the cementing material exposed to the oral environment and the greater is the plaque accumulation and loss of adhesion [15]. Furthermore, failure of cement seal allows for germs to build up in the marginal space and endangers the treatment's viability by causing pulpal necrosis, secondary caries, and pulpal inflammation [16]. Monolithic zirconia crowns have exceptional fracture resistance up to a point with a 0.5 mm thickness, according to the findings of *in vitro* experiments [8,10].

Several *in vitro* studies concluded that monolithic zirconia crowns showed greater mechanical characteristics compared with those of other ceramic materials [8–17]. Along with the elimination of chipping, monolithic zirconia crowns appear to have a distinct advantage in that less occlusal space is needed.

This study hypothesized that both margin designs do not influence the marginal accuracy and the fracture resistance of monolithic zirconia crowns.

2. Patients and methods

After gaining approval from the Research Ethics Committee (REC), Faculty of Dental Medicine for Girls, Al-Azhar University, Egypt, under code REC-CR-23-05, the study was carried out.

2.1. Sample size calculation

The G Power statistical analysis software (version 3.1.9.7) was used for calculating this study's sample size, according to Comlekoglu *et al.* [18]. A total sample size of 10 teeth (5 teeth per group) was adequate to figure out a significant effect size of 2.21, with an actual power (1-β error) of 0.8 (80%) and a significance level (α error) 0.05 (5%) for a two-sided hypothesis test.

2.2. Samples' grouping

A total of 10 samples were equally allocated into two groups based on the design of the finish line: group (A): Horizontal prep (with 0.7 mm deep chamfer), and group (B): Vertical prep (with 0.25 mm featheredge).

2.3. Metal dies construction

A lathe-cutting machine was used to construct stainless steel dies, to simulate tooth preparation for an all-ceramic restoration for a lower second molar. Every die had been prepared to have a total convergence of 12° (6° axial taper) with an occluso-cervical height of 5 mm and a root height (the unprepared portion of the die) of 8 mm. One die group was prepared according to standard preparation with a chamfer finish line (0.7 mm), whereas the other die group with a feather edge (0.25 mm). Each die has a non-anatomical occlusal surface, and a 45° occluso-axial beveling of 1 mm height was made to ensure the precise repeatability of the positioning of the crown copings and to avoid rotation of the crown copings over the dies.

2.4. Production of epoxy resin dies

Each stainless-steel die was duplicated to produce 5 replicas fabricated from epoxy resin material as follows: Silicon mold for master stainless steel dies had been created using a duplicating addition silicon material (Replisil 22 N, Germany). Each stainless-steel die was inserted in the center of a 20 mm diameter cylindrical Teflon container. According to the manufacturer's instructions, Replisil components A and B had been mixed at room temperature at a ratio of 1:1 for about a minute until a uniform color was achieved. The material was then poured into the Teflon container while being vibrated to prevent air entrapment. The silicon mold was removed from the Teflon container after the poured silicon had been in place for 30 min to solidify. The epoxy resin dies were separated from the silicon molds once they had fully hardened. The constructed dies were inspected for any irregularities or deficiencies.

2.5. Steps of katana zirconia crowns fabrication

2.5.1. Dies scanning

Before the scanning process, the epoxy resin dies were sprayed using the OKKLU-EXACT spray (OKKLU-EXACT Dent-e-Con e.K., Lonsee, Germany) to overcome the highlights from the dies surfaces and ensure an accurate impression. Then scanning of dies was carried out by Degree of Freedom scanning machine (DOFFREEDOMUH, DOF, Seoul, and Republic of Korea) which gives highly accurate results by the automated three-dimensional calibration. To record all needed details, the light module unit and the 2.0 MegaPixel camera move 0–90°, and the scanning plate allows for a 360° rotation around the scanning stage. After that, the scanned data were saved in open STL format that allowed to be processed by Computer aided design software. Following that, the finished data set is reloaded into the three-dimensional viewer to plan the restoration for each lower second molar die.

2.5.2. Designing

A virtual die appeared on the computer aided design/computer aided manufacturing machine screen (Imes-icore GmbH Germany) then the Exocad software (Exocad, GmbH, Germany) was used to start the designing step, where the finish line was traced, to check its thickness and determine the insertion access. An internal gap to provide space for cement was kept constant at 50 μm for all samples. The STL files of the designed crowns were saved and sent to the milling machine.

2.5.3. Milling of zirconia crowns

A 5-axis milling unit machine (Imes-Icore CORiTEC, GmbH Germany), which is a compact 5-axis dry and wet milling machine, was used for milling of KATANATM Zirconia ML blank (Kuraray Noritake Dental Inc. Japan) to produce ten single crowns ($N = 10$), five crowns for each group ($n = 5$). After that, each block was inserted in the workpiece spindle and tightened. After finishing the milling procedure each prosthetic restoration had been divided from the block. Then each restoration was fitted on the corresponding master die for checking of margin accuracy for any marginal discrepancy the sample would be excluded.

2.5.4. Sintering of zirconia crowns

The crown was then placed in a special furnace (Sirona HTC InFire Sintering Dental Lab Furnace, DenSply, Canada), with zirconia sintering beads (Z beads, Zirconia sintering Beads-Dental Creations, Ltd China) in a crucible crack tray (Alien crucible tray, Alien Milling Technologies, Glendora, Californi), with the occlusal surface facing down to complete the sintering process. The furnace was adjusted to 1500 °C/2732 °F with a hold time of 2 h and a temperature increase rate of 10 °C/18 °F min. This stage was required to achieve the restorations' final flexural strength and dimensions.

2.5.5. Glazing of zirconia crowns

The intaglio surface of the crowns was sandblasted by alumina air particles (Korox 50, Bego, Bremen, Germany) (50 μm, 30 psi, 0.2 Mpa) using a sandblasting machine (Cobra, Renfert GmbH, Hilzingen, Germany). An ultrasonic cleaner (CODYSON ULTRASONIC CLEANER CD-4820, China) in alcohol or acetone was used to clean the restorations. The surface of zirconia crowns was smoothed as fine as possible with a silicone diamond point (polierer – set zirko shine, oko dent Gmbh and Co.

KG, Germany) then glazing material (CERABIEN ZR FC Paste Stain, Kurary Noritake Inc., Japan) was applied.

2.5.6. Checking restorations fit

All crowns were checked over their corresponding dies, and inspected for marginal accuracy by eye and proper seating, any defective restoration was discarded.

2.6. Cementation of zirconia crowns

In this research, powder liquid hand-mixed glass ionomer cement (3 M Ketac Cem radiopaque Glass Ionomer Luting Cement; 3 M, ESPE, U.S.A) was chosen. First, a zirconia surface cleaner (ZirClean; BISCO, U.S.A) was used to improve the surface energy at the intaglio. The powder bottle was shaken to fluff the powder up, and one level scoop of powder was dispensed on the mixing pad, aside from two drops of the liquid. The powder was added to the liquid in one portion and mixed. When properly mixed, the glass ionomer cement should stretch ½' from the pad, an indication that it is ready to be placed on the fitting surface. The mixture was applied evenly on the inner surface in thin sections. A specially designed device made from wood was constructed to standardize load application (3 kg) while undergoing the cementation procedure. A sharp probe was used for excess cement removal.

2.7. Thermal aging

The total number of cycles utilized in this study was 2500 cycles equivalent to 3 months. For every water bath (Robota automated thermal cycle; BILGE, Turkey), Dwell times were 25 s and lag time was 10 s. The low temperature point for the current study was 5 °C whereas the high temperature point was 55 °C.

2.8. Testing procedures

2.8.1. Marginal gap determination

With the aid of a USB Digital microscope that has an integrated camera (U500 × Digital Microscope, Guangdong, China) every sample was photographed for marginal gap assessment. The following image acquisition technique was implemented. A 3 MP digital camera had been set vertically, 2.5 cm apart from the samples. The lens axis was adjusted to be in a 90° angle with the illumination source. The illumination source used for photographing was eight LED lamps (Adjustable by Control Wheel), that have a color index of approximately 95%. The photos were captured at the highest resolution with a fixed magnification of 40× and transferred to an IBM-compatible personal computer. The images were recorded with a resolution of 1280 × 1024 pixels per image as shown in Fig. 1. The marginal gap width was assessed and measured using a digital image analysis software (Image J 1.43U, National Institute of Health, USA) in which, sizes, limits, and frames in addition to all variables measured are expressed in pixels. System calibration was therefore performed to translate these pixels into precise real-world units. For this Calibration, in the current study, a known-size ruler was compared with a scale produced by the Image J software. For every sample, photos of the margins were obtained. Then from each shot, morphometric measurements (by identifying three equally spaced landmarks along each aspect's circumference) were taken. Measurement at each point was repeated three times. Then the data obtained were collected and collated for statistical analysis.

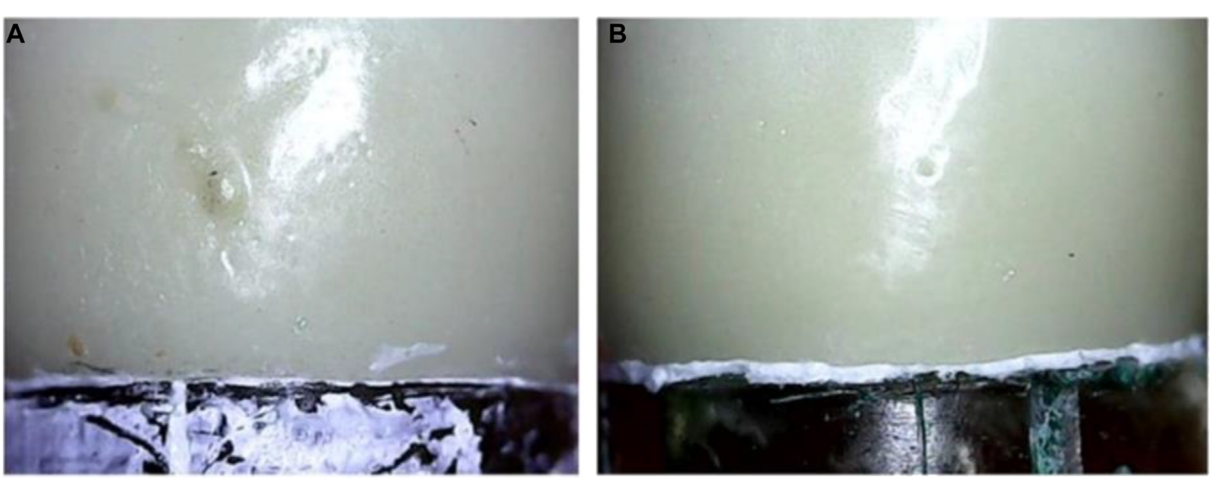

Fig. 1. Digital microscopic image for a marginal gap of (A) feather edge design, (B) deep chamfer design.

2.8.2. Fracture resistance test

The computer-controlled materials testing apparatus (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a 5 KN load cell was used to test each sample separately. Bluehill Lite programme (Bluehill Lite programme, Instron) was used to record the data. By tightly fastening screws, samples had been firmly mounted to the lowest fixed compartment of the testing apparatus. Fracture test then implemented by applying a compressive load occlusally. This compressive load was applied utilizing a metallic rod hat has a round tip (5.8 mm diameter) and fixed to the upper moving compartment of the testing machine running at a crosshead speed of 1 mm/min. A tin foil sheet is placed in between to ensure equal stress distribution and minimize local force peaks from being transmitted as shown in Fig. 2. The load at failure is indicated by the presence of an audible crack and confirmed by a steep drop at the load-deflection curve recorded by the software (Bluehill Lite Software, Instron). The load essential to cause fracture was measured in Newton units.

2.9. Statistical analysis

Values of marginal gap and fracture load were presented as mean and standard deviation (SD) values. Statistical analysis was performed using SPSS Ver.28 statistical software (SPSS Inc., Chicago, IL, USA). The data was compared statistically using LSD at the level of $P \leq 0.05$. χ^2 test was used to compare mode of fracture between groups.

Fig. 2. Sample in universal testing machine for fracture resistance test.

3. Results

3.1. Statistical analysis of marginal accuracy

Regarding the marginal gap distances, the Featheredge group recorded lower mean marginal gap values (77.01 ± 9.76 μm) than the Chamfer group (84.17 ± 9.87 μm). However, the difference was statistically insignificant by using the Independent *t*-test ($P > 0.05$), (Table 1).

3.2. Statistical analysis of fracture resistance

Regarding the fracture load, the Featheredge group showed lower mean fracture load values (629.26 ± 101.25) than the Deep chamfer group (1278.14 ± 519.08). The difference was statistically significant by using Independent *t*-test ($P = 0.02$), (Table 2).

4. Discussion

In order to ensure standardization, the same operator performed each procedure in the current investigation. Each stainless-steel die was prepared to have a vertical height of 5 mm and a convergence angle of 12° [19]. Preparation with a convergence angle of 12° has been shown to achieve the optimum precision of zirconia restorations in the range of 36.6 and 45.5 μm [20]. To precisely reposition the crowns during cementation, the occluso-axial line angle was beveled at one side of the die during the production of an all-ceramic restoration.

Ten epoxy resin dies were used in the current study. Epoxy resin material was proven to have an elastic modulus similar to that of natural tooth dentin. In addition to that, the epoxy resin material

Table 1. Minimum, maximum, mean, and standard deviation of marginal gap (μm) in both groups and comparison between them.

	Chamfer (ontrol group)		Featheredge (Intervention group)		*P* value
	Mean	Standard deviation	Mean	Standard deviation	
Mesial	89.98	17.65	80.78	11.41	0.18 ns
Lingual	77.52	19.27	65.74	33.01	0.34 ns
Distal	86.43	14.43	83.73	11.34	0.64 ns
Buccal	82.76	13.07	77.78	8.21	0.32 ns
Overall	84.17	9.87	77.01	9.76	0.12 ns

Ns: nonsignificant difference as *P* greater than 0.05.

Table 2. Minimum, maximum, mean, and standard deviation of fracture load (N) in both groups and comparison between them.

	Fracture load (N)				*P* value
	Minimum	Maximum	Mean	Standard deviation	
Deep chamfer (Control group)	965.75	2200.72	1278.14	519.08	0.02*
Featheredge (Intervention group)	527.14	747.63	629.26	101.25	

*Significant difference as *P* less than 0.05.

demonstrated high availability and dimensional stability [21]. The use of extracted human teeth as specimens can offer greater accuracy than resin abutments since they mimic the intraoral environment. However, it is challenging to standardize natural teeth due to several characteristics, including age, anatomy, size, form, and time spent in storage following extraction [22].

Other die materials have been used in literature, including composite resin and metallic dies. Although these materials can be readily controlled and standardized, a study conducted by Jian *et al.*, demonstrated that cementation of zirconia prostheses to resin dies showed lower fracture load values than crowns cemented to porous titanium and natural dentin [23].

In comparison to veneered zirconia restorations, second generation monolithic zirconia restorations (multi layered zirconia) demonstrated a significant reduction in technical complexity. Additionally, since a veneer layer is not necessary, monolithic zirconia can be used in thinner layers, helping to preserve more tooth structure [24].

Monolithic zirconia materials are readily available in a different versions; the translucency of zirconia is obtained by decreasing the number of alumina particles. The lowered alumina proportion allowed for increased translucency in second generation zirconia (multilayered zirconia) with almost unaffected mechanical qualities compared with first generation zirconia [24].

Third generation yttria stabilized monolithic zirconia (STML and UTML) showed better translucency and esthetics than second generation (multi layered zirconia) but lower mechanical properties [25].

In an attempt to simulate the layered porcelain appearance in full monolithic zirconia restorations, multilayered zirconia displayed a multilayering gradation consisting of four gradation layers (35% in the enamel, 15% in the first layer, 15% in the second layer and 35% in the dentin) [26].

Artificial aging in this study was 2500 thermal cycling equivalent to 3 months. It has been found that temperature fluctuations during the thermomechanical aging process have resulted in the washing out of some of the cement at the prosthetic margin and a subsequent significant increase in the vertical marginal discrepancy [27].

A key element essential for the success and long lasting survival of prosthetic restorations is the achievement of precise internal and marginal fit [28]. Numerous approaches have been used for evaluation of the prosthetic fitting, such as microtomography, the direct view technique that uses an external microscope, the replica technique, the cross-sectioning technique and profile projector technique [29]. It has been found that the replica technique and the use of internal microscopes are the most widely used approaches for evaluating the internal fit of zirconia restorations, whereas the use of external microscopes is most widely used for the evaluation of the marginal fit.

Being the least amenable to correction after completing the prosthetic fabrication, the vertical marginal gap was chosen as an assessment measurement in the current investigation for evaluating how well zirconia restorations fit. On the other hand, prosthetic overhangs and other horizontal discrepancies can be corrected intraorally to some degree [15].

For accurate and precise evaluation of marginal fit of zirconia restorations that had been used in the current study, a digital microscope was used for this purpose. Digital microscopes offer high viability and practicality in a nondestructive nature and thus serve the purpose of accurately assessing the fit of all prosthetic margin [14].

According to the study's findings on marginal gaps, no statistically significant difference was noted between the deep chamfer preparation and the featheredge preparation. Consequently, the different margin designs do not influence the marginal accuracy of monolithic zirconia prostheses. Therefore, the first part of the study hypothesis was accepted.

It is worth mentioning that, the featheredge design showed a statistically non-significant lower marginal gap mean value (i.e., better marginal adaptation) than the deep chamfer margin design (i.e., less marginal adaptation), (Table 1). However, the marginal discrepancies of both groups were within the clinically acceptable threshold of 120 μm as reported by McLean and Fraunhofer 1971 [30].

The lower marginal gap values of featheredge group can be explained by the fact that the gap between the prosthetic margin and the tooth gets smaller when the restoration margin is at a more acute angle [20,27]. Despite this, in clinical practice, shoulder and chamfer preparations were recommended from technical and biological perspectives, citing the featheredge design causes marginal wedging effect and thus contributing to additional bulk at the crown margin [18].

The findings of the current study come in accordance with the results of the study that was conducted by another study [31], which found no statistically significant difference between both preparation designs or between different cement gap thicknesses. Also, another study reported that the clinical outcomes of crowns made from zirconia with feather-edge marginal design were similar to those provided with other marginal designs but with decreased preparation invasiveness [32].

In contrast, the data obtained from the current study are inconsistent with those obtained from another study [14], which reported better outcomes with a 1.0 mm finish line in contrast to the 0.5 mm finish line. This was most likely because of the lower internal stresses associated with the preparation of the 1 mm finish line that allowed for the accommodation of greater zirconia bulk compared with the 0.5 mm finish line.

In contrast to the results of this study, another study [33] reported that feather edge marginal design had resulted in inadequate internal and marginal fits of ceramic restorations.

These contradictions between this study and other studies may be due to the different measurement methods and the location of the reference points used the testing conditions, and the use of different ceramic types.

Regarding the fracture resistance, the featheredge margin design recorded statistically significantly lower fracture load values (629.26 $\pm$ 101.25 N) than the deep chamfer design (1278.14 $\pm$ 519.08 N), (Table 2). Consequently, the different margin designs have a significant impact on the fracture resistance of monolithic zirconia crowns. Therefore, the second part of the study hypothesis was rejected.

The results of this study are concurrent with other studies [1,34–36] which contributed these results to the greater bulk of the restoration that bears the masticatory loads and thus less stress is concentrated along the prosthetic axial walls. In addition, another study reported lower fracture resistance of monolithic zirconia crowns with vertical preparations compared with the horizontal (shoulder) preparations [37].

Moreover, the fracture strength of the zirconia restorations in both study groups demonstrated a greater capability of bearing loads higher than the human average maximum masticatory forces to the FPD (500–600 N in the posterior area), This can be because of zirconia's improved mechanical characteristics, which are beneficial for minimal preparations [38,39].

The results of this study are at contrast with other studies [40,41] which showed significantly higher fracture resistance associated with the vertical designs. This could be explained by the pattern along which stress is distributed during loading. They assumed that, under increased loading, the crown could slide down the axial wall of the dies that lack definite margins without being limited by the margin, and stresses were concentrated on the occlusal surface in the fractographic analysis.

4.1. Limitations of the study

Limitations of the current study are the use of epoxy resin dies for assessing the marginal gap. Despite allowing for standardization, epoxy dies does not mimic the human's intraoral environment. Another limitations is the inability of measuring the horizontal marginal gap and internal fit, as this requires sectioning of specimens, also using straight instead of curved finish line (mesio-distally and bucco-lingually) which might give different results. Moreover, specimens were not subjected to chewing simulation, and oral conditions were not simulated by applying mechanical loadings.

4.2. Conclusions

Within the limitations of this study, it was concluded that the marginal accuracy of monolithic zirconia crowns with featheredge margins is like that with deep chamfer and that featheredge margins have an adverse effect on the fracture strength of monolithic zirconia prostheses; however, the fracture load values are within the accepted levels.

Also, vertical preparation offers a valuable conservative alternate to horizontal preparation when it is used for the construction of monolithic zirconia crowns.

4.3. Recommendations

In light of the present study, the vertical preparation design can provide an accepted alternative to horizontal preparation regarding vertical marginal fit and fracture strength. Further clinical studies on vertical preparation are needed.

Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Conflicts of interest

There are no conflicts of interest.

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