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MARGINAL INTEGRITY OF MONOLITHIC ZIRCONIUM OXIDE CROWNS WITH TWO MARGINAL DESIGNS: (AN IN-VITRO STUDY)

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ABSTRACT

Aim: The aim of this study was to assess the marginal integrity of monolithic zirconium oxide crowns with two marginal designs (chamfer and edgeless).

Materials and methods: Two maxillary right second premolar typodont teeth were prepared with 2 finish line designs (Chamfer and Edgeless) to receive 22 monolithic zirconia crowns. The crowns were divided into 2 groups according to the design of the finish line (n=11). Preparations were directly scanned, crowns were designed using Exocad software, milled using a five-axis milling machine and checked for seating under magnification. Stereomicroscope and image analysis software were used to measure the vertical marginal gaps (VMG) and marginal chippings. Calculations for the mean VMG and the chipping factor (CF) of each crown were tabulated for statistical analysis.

Results: The crowns of chamfer group were associated with VMG mean value (12.85 ± 2.42 µm), while, those of edgeless group recorded (11.42 ± 0.73 µm). Independent t- test revealed no statistically significant difference between the two groups. Regarding CF measurement, chamfer group recorded mean value (0.21 ± 0.62), while the edgeless group recorded (2.92 ± 2.57). Mann-Whitney U test was performed and revealed a statistically significant difference with value (p=0.001) between chamfer group and edgeless group.

Conclusions: Monolithic zirconia with chamfer and edgeless finish line preparation designs proved to have high marginal accuracy below the clinically accepted values of CAD/CAM restorations. Edgeless margin had higher chipping tendency in comparison to chamfer margin.

KEYWORDS: Chamfer Finish Line. Edgeless Finish Line. Monolithic Multilayer Zirconia. Vertical Marginal Fit. Chipping Factor.

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INTRODUCTION

Esthetically and functionally ideal restorations are determined by 3 main factors: esthetic value, resistance to fracture, and marginal adaptation[1]. Marginal gaps increase risk of carious lesions, cement resolution, pulpal inflammation, and periodontal diseases[2]. Marginal gaps of restorations are influenced by many factors, a crucial one of them is the margin design, but how it affects the final outcome is still debatable[3].

Finish line preparation designs are divided into two main categories: horizontal and vertical. The horizontal type includes shoulder and chamfer finish lines, while the vertical type includes shoulderless and edgeless. The edgeless type 'biologically oriented preparation technique' (BOPT) is gaining popularity, but needs more research to approve its efficiency[4].

In clinical situations including root canal treated teeth, young vital teeth or teeth with short clinical crowns such as: mandibular incisors, and cervical caries-affected teeth, vertical preparations provide a more conservative option to horizontal margin design. In addition, vertical preparations are more indicated for patients with advanced periodontal disease and attachment loss[5]. However, some drawbacks of vertical preparation have been noticed like overhangs, over-contouring, unpredictable tissue healing and a higher rate of bleeding on probing than chamfer preparations[6]. Moreover, the liability to chipping fracture of the restorations have always complicated the decision to use vertical preparation designs[7]. Nowadays, CAD/CAM technology-based minimally invasive preparation designs have been found to be an effective treatment option, providing fixed prosthodontists with ideal marginal quality restorations[8].

Comlekoglu et al.[3] mentioned that the knife edge vertical design has the advantage of smaller vertical gap between the margin of the restoration and the finish line of the abutment. Poggio et al.[9] came to the same conclusion that knife edge margins are comparable to other margin designs in their clinical performance. On the other hand, Salem and Asaad [10] reported that vertical finish line had significantly higher marginal gap than the horizontal finish line. The key factor in evaluating the crowns' marginal gap is the range of the maximally accepted value for dental restorations. Demir et al.[11] reported that 50-120 µm is considered clinically acceptable marginal gap value of CAD/CAM restorations.

The esthetics and translucency were greatly enhanced in the newer forms of monolithic zirconia, allowing them to be milled in thin sections while maintaining their high mechanical properties[12]. Apart from the precision of margins' fit either vertically or horizontally, the edge quality—which is determined by being smooth and free of chippings—has a major impact on the clinical lifespan of monolithic zirconia restorations[13]. One study by Li et al. [14] reported that vertical margin of monolithic zirconia crowns showed more chipping defects than horizontal designs. However, it should be noted that studies evaluating the chipping behavior of crowns are scarce, although this property is crucial

The null hypothesis of the present investigation is that there will be no difference in the marginal integrity (vertical marginal gap and edge chipping) of full coverage restorations constructed from monolithic zirconium oxide with two different finish line designs (edgeless VS chamfer).

MATERIALS & METHODS

Methods

Ethical statement:

This in-vitro study was conducted in the Cairo Digital Dental Center, Faculty of Dentistry, Cairo University, Egypt according to the recommendations and approval of the ethics committee on in-vitro research of Faculty of Dentistry, Cairo University with an approval number of 13-7-20.

Sample size calculation:

A power analysis was designed to have adequate power to apply a 2-sided statistical test of the research hypothesis (null hypothesis) that no difference in the marginal accuracy of full coverage restorations constructed from monolithic zirconium oxide with two different finish line designs (edgeless VS chamfer). By adopting an alpha (α) level of 0.05 (5%), beta (β) level of 0.20 (20%) i.e. power=80% and an effect size (d) of (1.27) calculated based on the results of Eldamaty et al.[15] (2020); the predicted sample size (n) was found to be a total of (22) samples i.e. (11) for each group. Calculation of sample size was performed using G*Power version 3.1.9.7

Samples grouping

A total of twenty-two samples were divided into two groups (eleven in each group) according to the type of the finish line as follows:

- **Group (Chamfer):** (n=11) Crowns fabricated with chamfer finish line (control).

- **Group (Edgeless):** (n=11) Crowns fabricated with edgeless finish line.

Typodont Teeth Preparation:

Maxillary right second premolar (NISSIN Dental Model, Koyoto, Japan) was selected for the preparation to receive monolithic zirconia restoration, an addition silicone putty index (Silagum, DMG, Germany) was taken before the preparation to ensure that the preparation is standardized and with the use of magnifying loupes 3X (Univet 3.0 X, Italy), a single operator performed both types of preparations. An occlusal depth cut stone (PrepMarker 1.5mm, Komet, USA) was used for occlusal reduction.

Regarding **Chamfer group**, the tooth was prepared to have chamfer finish line (0.5mm) using Coarse and fine grit tapered stones with round end (Komet Dental, USA).

Regarding **Edgeless group**, the tooth was prepared to have edgeless finish line placed equigingivally. The tool used for this preparation were special designed medium and fine grit batt burs (Komet Dental, USA)[16].

EVE Diacomp plus occluflex (EVE, Germany) and 3M Sof-Lex polishing spiral wheels (3M, USA) were used to polish both preparations.

Preparation Taper Verification:

A digital camera (Nikon D7200 Digital SLR camera, Japan) with 24.2 mega pixels was mounted perpendicular to the long axis of the typodont tooth. By using a water level ruler to ensure its position perpendicular to the floor, the tooth was set at a distance of 25 cm from the camera. Photographs of the two typodont teeth were taken from the buccal and proximal aspects in standard conditions by a single investigator. After transferring the photos to a PC, the taper angle was calculated using the AutoCAD 2007 program. Lines were drawn along the right and left outlines of the tooth's axial walls in each photograph, with the mid-mesial and mid-distal lines representing the buccal view and the mid-buccal and mid-lingual lines representing the proximal view. Two lines were drawn for each axial wall: one line extended from the finish line parallel to the tooth's longitudinal axis, while the other line extended from the same finish line position parallel to the axial wall.

The angle formed by the two lines was measured to determine the taper angle of the axial wall. Both typodonts were prepared with their total occlusal convergence 12° (6° per axial wall).

Restoration fabrication:

Each of the typodont teeth was scanned with an intraoral scanner (Primescan, Dentsply Sirona, Germany), then model images obtained on the scanner were exported through Cerec connect software & Inlab 19 (Dentsply Sirona, Germany) in

PLY format to EXOCAD software (3.0 GALWAY) (Exocad GmbH, Germany) where an upper right 2nd premolar tooth was selected, followed by selection of anatomic crown of Zirconia Multilayer material (Mammoth Zirconia 3D Pro Multilayer, China). Since the 2nd premolar is still considered in the esthetic region, the material's choice can fulfill both esthetic and functional demands with translucency ranges between 42% - 49% and flexural strength ranges between 650 -1100 Mpa. Chemical Composition of the material is $ZrO_2 + HfO_{2\,+}\,Y_2O_3 = 99\%$, Y_2O_3 (4.5% – 10%), Al_2O_3 (< 0.15%), Other Oxides (< 0.5%). Regarding spacer thickness, it was set at 50μm.

Margin line detection was done and confirmed by an arrow pointing at exact position of finish line in a 2D image as a valid method offered by EXOCAD. Designing of crowns regarding position, shape and contour was completed.

CAD file of virtual design was exported to Ceramill Match 2 software (Amann Girrbach AG, Austria). Ceramill Match 2 software was used for nesting the restorations in the blank.

A five-axis milling machine (Ceramill motion 2, Amann Girrbach AG, Austria) was used. Milling was done in dry milling mode to produce zirconia crowns with 0.5 mm margin thickness for the chamfer group & with 0.2mm margin thickness for edgeless group. Monolithic zirconia's high flexural strength allows its milling in thin sections [17].

Milled zirconia crowns were sintered using inFire HTC speed furnace (Sirona, Germany) following the sintering diagrammatic chart provided by the manufacturer.

Restoration verification under microscope

One crown of each group "Pilot sample" was milled and checked for full seating on its corresponding typodont die before proceeding in production of total number of crowns. Easy view 3D (3D video microscope, Renfert, Germany) was used to check the seating of the restorations under 20X magnification.

Regarding chamfer preparation:

A) Spacer was set at 50 μm with margin free spacer (0.5mm): Restoration wasn't fully seated on the typodont die.

B) Adjustment was done so that, spacer was set at 70 μm with 0.5mm margin free spacer: The restoration was fully seated on the typodont die. After confirmation of full seating of the restoration, 10 crowns were then milled at 70 μm with 0.5mm margin free spacer.

Regarding edgeless preparation:

A) Spacer was set at 50 μm: Restoration wasn't fully seated on the typodont die.

B) In order to standardize CAD SW variables including design & parameters values, spacer value was set at 70 μm and another sample was milled and tested for seating: The restoration was fully seated on the typodont die. After confirmation of full seating of the restoration, 10 crowns were then produced.

Marginal accuracy measurement:

For every typodont tooth, a total of twenty marginal accuracy evaluation points were measured at five equally spaced locations on each of the four axial surfaces, so that marginal accuracy measurement of all crowns is measured at the same points using Stereomicroscope (Leica S8 APO, Germany) at 40X magnification. Specimens with edgeless preparation were marked at the finish line position with the side of a sharp red pencil to facilitate the detection of the vertical marginal gap under microscope.

All specimens were held in place using specially designed holding device.

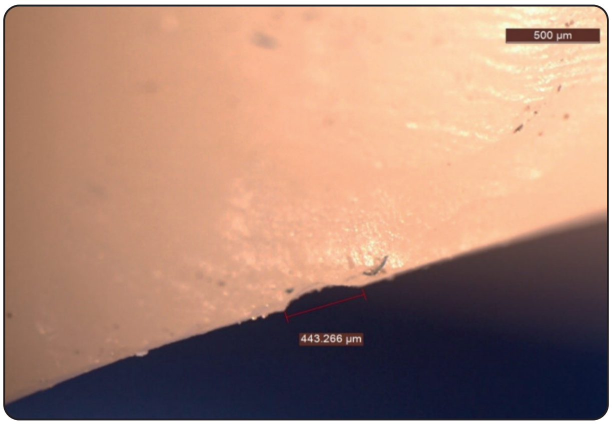

Fig. (1) Marginal chipping measurement using Leica Application Suite, LAS Core at 40X magnification

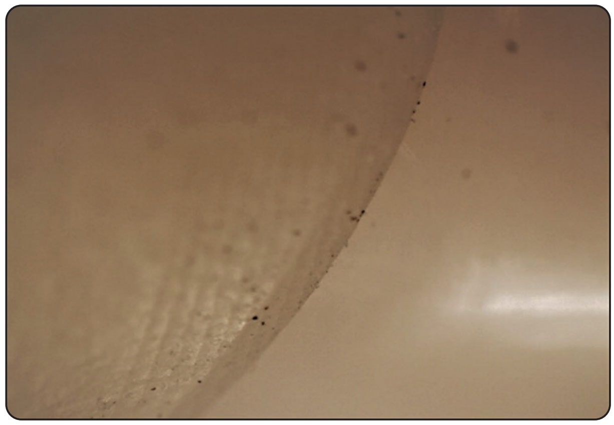

Fig. (2) No visible marginal gap discrepancy at 40X magnification in edgeless preparation

A digital image analysis software (Leica Application Suite, LAS Core, Germany) was used for marginal gap discrepancy measurement and to evaluate the amount of marginal chipping in each restoration (Figure 1 & 2).

Measurements were carried out for all the specimens, tabulated and statistically analyzed.

Chipping factor measurement:

As previously mentioned in two earlier studies by Gianntopoulos et al.[18](2010) and Tsitrou et al.[13](2007), the percentage of chipping was obtained by calculating the chipping factor of each restoration using the following equation:

CF= L/P x100

Where, L is the amount of marginal chipping and P is the restoration margin's circumference multiplied by 100.

Digimizer image analysis software (Digimizer Version 5.7.2, MedCalc Software Ltd, Belgium) was used to measure the peripheral circumference (P) of the restoration after a top view image of each crown's margins was captured with a digital camera (Nikon D7200 Digital SLR camera). Every restoration's chipping factor (CF) was noted and tabulated for statistical analysis.

RESULTS

Marginal Gap

Checking the Normality of Data:

The marginal gap for both research groups (chamfer and edgeless groups) was shown to be normally distributed using the Kolmogorov-Smirnov and Shapiro-Wilk's tests. Assuming that significance value ($p>0.05$) of these normality tests indicates normal distributed data. The P-value for the edgeless group was 0.145 and for the chamfer group was 0.09, according to the Kolmogorov-Smirnov test. Additionally, the P-value for the edgeless group was 0.45 and for the chamfer group was 0.136 according to the Shapiro-Wilk's test.

Parametric Test (Independent t-test):

The chamfer group was recorded to be associated with vertical marginal gap mean values =12.85μm (SD=2.42). While, the marginal gap mean values in edgeless group were =11.42 μm (SD=0.73). Independent t- test revealed no statistical significant difference between chamfer group and edgeless group with recorded significance (2 tailed) value=0.122 Table (1). A graphical presentation of the mean differences was shown in figure (3).

TABLE (1) Illustrating the descriptive analysis of the study groups

Group Statistics								
	Study groups	Mean	Std. Deviation	Std. Error Mean	Levene's test		t-value	P-value
					Value	Sig.		
Marginal gap	Chamfer group	12.85	2.42	0.81	8.95	0.009	1.69	0.122
	edgeless group	11.42	0.73	0.24				

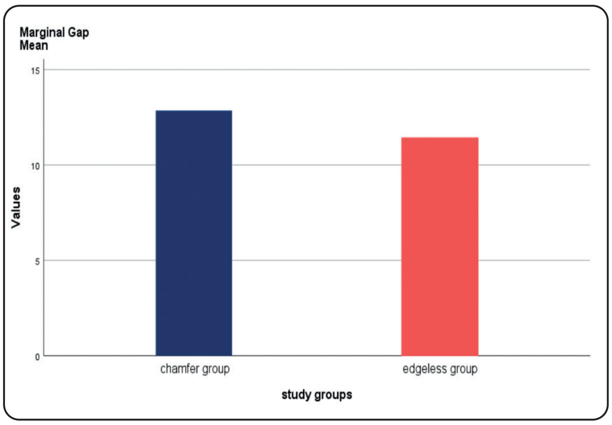

Fig. (3) Bar chart representing the mean differences of the marginal gap between chamfer group and edgeless group

Chipping Factor

Checking the Normality of Data:

The chipping factor for both study groups (chamfer and edgeless groups) was shown to be normally distributed using the Kolmogorov-Smirnov and Shapiro-Wilk's tests. Assuming that significance value (p>0.05) of these normality tests indicates normal distributed data. The P-value for the chamfer group was 0.00, whereas the edgeless group's P-value was 0.20, according to the Kolmogorov-Smirnov test. Also, the Shapiro-Wilk's test showed that the edgeless group's P-value was 0.017 and the chamfer group's P-value was 0.00.

Non parametric test:

The chamfer group was recorded to be associated with chipping factor mean values of 0.21 (SD= 0.62). While, the chipping factor mean values in edgeless group were recorded to be 2.92 (SD=2.57).

To test the hypothesis that chipping factor in chamfer group and edgeless groups was associated with statistically significant difference of their means, a Mann-Whitney U test was performed as seen in table (2). The test revealed a statistical significant difference with value (p=0.001) between chamfer group (median=0) and edgeless group (median= 2.15) and U=3. The effect size calculated as (r- value =0.82) revealed large effect size. A graphical presentation of the mean differences was shown in figure (4).

TABLE (2) MannWhitney U Test Results

Group Statistics							
	Study groups	Mean	Std. Deviation	Median	Mann-Whitney U test	P-value	Effect size (r value)
Chipping factor	Chamfer group	0.21	0.62	0	3	0.001	0.82
	Edgeless group	2.92	2.57	2.15			

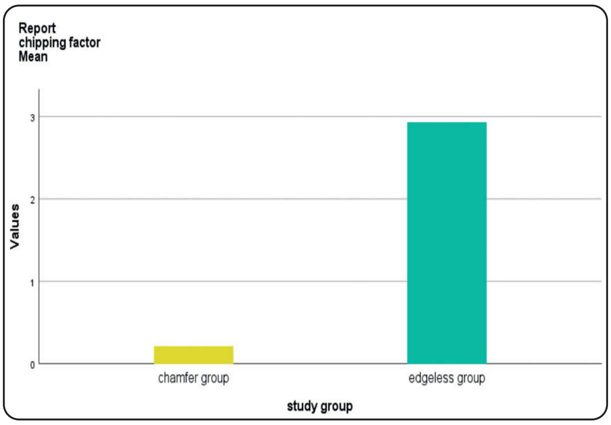

Fig. (4) Bar chart representing the mean differences of chipping factor between chamfer group and edgeless group

DISCUSSION

Dental hard tissue is irreversibly lost during invasive teeth preparation receiving full coverage restoration. In an effort to preserve more tooth structure throughout the preparation process and obtain an acceptable marginal fit and emergence profile, numerous attempts have been undertaken to determine the optimal way to prepare teeth. One of these attempts is the vertical preparation, which is advised as a more conservative option to horizontal preparation (shoulder or chamfer) in full coverage restorations where monolithic zirconium oxide crowns are planned and the finish line may be extremely thin[4]. Vertical preparation might achieve all goals but the available data about its marginal integrity is scarce.

Full-contour monolithic zirconia restorations have grown in popularity because of its excellent mechanical properties related to the transformation toughening mechanism. Furthermore, because of its high flexural strength, it can be machined with a reduced thickness, providing adequate strength even for posterior fixed dental prostheses[17].

It is not yet known whether using thin monolithic zirconia with more conservative edgeless preparation design would affect the marginal integrity of the restoration which is considered an essential criterion to ensure long term success of the restoration. Therefore, the aim of this study was to assess the marginal accuracy and chipping factor of monolithic zirconium oxide crowns with chamfer and edgeless marginal designs.

Special burs for vertical preparation (batt bur) were used in the current study for vertical (edgeless) preparation. It is a tapered diamond bur with rounded non-cutting end. Its design is different from the flame burs employed in both the Mascarella's school approach and the biologically oriented preparation method (BOPT). This bur provides a number of benefits over flame burs, such as a 2° taper that allows a degree of taper of the abutment and a non-cutting (safe) end of 1 mm that doesn't cause violation of the biologic width and damage to the connective tissue attachment. Also, permits a bloodless gingitage and working without ripping or impingement of the retraction cord or Teflon tape[16].

Data were sent to EXOCAD software (3.0 GALWAY) to design the restorations for both type of preparations. Finding the ideal location for the initial seed point for the automatic margin line identification process is one benefit of utilizing Exocad software, particularly during margin line detection and presenting it in a 2D sectional image for confirmation. This is highly crucial and beneficial with edgeless preparation design as it helps to detect the outermost point which corresponds to the vertical finish line.

In the light of the marginal gap test results, the null hypothesis of this study was accepted as there was no difference in the marginal accuracy of monolithic zirconium oxide full coverage restorations with 2 different finish line designs (edgeless VS chamfer).

All the tested crowns' marginal gap results were below the range of the clinically accepted value 50-120 µm [11]. It was found that edgeless margin design recorded statistically non-significant lower marginal gap mean value (11.42±0.73µm) than chamfer margin design (12.85±2.42µm).

This was in agreement with the findings of a study by Comlekoglu et al.[3](2009), which examined the impact of four different finish line designs (chamfer, mini-chamfer, feather edge and rounded shoulder) on veneered zirconia crowns' marginal fit and results were similar to the current study. They claimed that the more the margin of the restoration ends with an acute angle (knife edge), the shorter the distance between the restoration margin and the tooth.

This was also consistent with the findings of Poggio et al.[9](2012), who found that zirconia crowns layered with feldspathic porcelain with knife edge margins performed well in a general dental practice, and that clinical performance was comparable to data recorded with other margin designs.

Same findings also have been reported by Nasir and Kadhim[19], recording a higher pre-and post-cementation marginal gap for the chamfer preparation design, with a significant difference from the vertical design. This may be explained by the curved (concave and convex) surfaces of a chamfer finish line which could make milling the crown restoration more challenging, and subsequently lowering the marginal fit.

In reference to to the chipping factor results, the mean values of the chipping factor for the chamfer group were found to be (0.21 ± 0.62) compared to the chipping factor values in edgeless group (2.92 ± 2.57). Edgeless group recorded statistically significant higher chipping factor than in chamfer group.

This was in agreement with Li et al.[14] (2021), who assessed the accuracy of fabrication and chipping behavior of milled monolithic zirconia crowns with three different finish line designs (rounded shoulder, chamfer and knife-edge) and knife edge margin showed more chipping defects than other designs. It has to be noted that margin quality was evaluated at 200X magnification.

On the contrary, Hasan N H et al.[20] (2024) examined the marginal chipping factor of multilayered zirconia restorations with two different thicknesses (0.3 – 0.5 mm). It was reported that there was no significant difference in the chipping factor between 0.5 mm and 0.3 mm thicknesses.

A remarkable finding in our study is that there were sites in the edgeless preparation crowns where no gaps could be detected. Upon close observation to the seating of crowns on prepared tooth, there was slight overseating of crowns (crown seated at a deeper level) as the marked vertical finish line disappeared in some of the samples which can be explained due to the absence of horizontal finish line which can act as a stop or bottom line together with the presence of uniform cement space occlusally and radially. This could explain that despite of the higher chipping factor of edgeless design, it showed non significantly better marginal accuracy.

Thanks to the Vertiprep, monolithic zirconia, and significant CAD/CAM technological breakthroughs, a conservative prosthetic approach with extremely predictable marginal adaptation is now possible. However, attention must be paid to the quality of the milling machine, milling burs, and restoration handling to reduce risks of chipping.

CONCLUSIONS

Within the limitations of this study, the following could be concluded:

1- Using zirconium oxide material with chamfer and edgeless finish line preparation designs proved to have high marginal accuracy below the clinically accepted values of CAD/CAM restorations.

2- Edgeless preparation design showed to have higher chipping tendency in comparison to chamfer preparation design.

RECOMMENDATIONS

1. Performing the same study design in a clinical environment.
2. Designing same research directed towards investigating the marginal accuracy and

mechanical performance of crowns after cementation.

3. Designing a research study comparing marginal accuracy of edgeless preparation design with different occlusal spacer thicknesses and different axial wall convergence.
4. More biological testing is required with restorations supported by edgeless preparation geometries.

DECLARATIONS

Conflict of Interest

Authors have no conflict of interest to declare.

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