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The impact of finish line design on the resistance to chipping of implants-based monolithic zirconia veneers

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Abstract
Introduction: One of the major problems of all ceramic restorations is their probable fracture against the occlusal force. The aim of the present in vitro study is to compare the effect of two marginal designs (shoulder, chamfer) on the fracture resistance of monolithic zirconia crowns.
Materials & Methods: Two premilled abutments of the dio system were selected and customized by the abutment design software (Exocad). Then, the abutments are prepared and scanned by the arumm machine. The design of the covers was done by the software (Exocad). The veneer coordinates were transferred to the device and 8 premolar veneers were made on two abutments for the implant with a diameter of 5 mm. One of the abutments was prepared with a shoulder cut margin and the second abutment with a chamfer margin, and after scanning the data, they were transferred to the CAD-CAM machine (Laserdenta, Germany) to make the veneer.
Results: In this study, 8 samples were prepared and compared. The samples were divided into 2 chamfer (number = 4) and shoulder (number = 4) groups and were subjected to the force of 30 Newtons. The crack length in all samples was 551.025 ± 74.8 mm. There was no significant difference in the average crack length in both groups.
Conclusion: The result of this study indicates that shoulder marginal design causes increasing the fracture resistance of zirconia crowns.
Keywords: Marginal Designs, Fracture Resistance, Monolithic Zirconia.

Introduction

One of the most prevalent issues with all-ceramic veneers is their susceptibility to fracture when subjected to occlusal and lateral forces. This problem arises due to the limited mechanical properties of the materials used, as well as the increased bite force in the molar and premolar regions and the inherent fragility of ceramics. The success or fracture of the restoration depends on the material's resistance to fracture, the design of the cutting margin, and the appropriate thickness of the material (1,2). In the field of dentistry, zirconia has gained significant recognition as a common choice for restorations. Restorations based on zirconia have demonstrated favorable mechanical properties, biocompatibility, and the potential for aesthetic appeal (2,3). Zirconia finds extensive applications in dentistry, serving as a framework, abutment, and monolithic veneer, owing to its high surface hardness, strength, resistance to wear, and low thermal conductivity (4). However, conventional zirconia lacks translucency and opacity, making it challenging to achieve a natural tooth color match. To overcome this limitation and attain similar color and translucency as natural teeth, the framework is fabricated using feldspathic porcelain (5). Clinical studies have revealed various issues associated with veneered zirconia frameworks, including: 1) susceptibility to rebound due to low strength (6-8); 2) a complex layering process; 3) weak bonding between the veneer and the core, resulting in veneer separation; and 4) tensile stress during veneering leading to porcelain and zirconia bond fracture (6,9-11). To address these problems, the introduction of monolithic zirconia for clinical treatments proved to be a solution. Monolithic zirconia is produced using CAD/CAM technology and eliminates the need for a porcelain veneer layer (5,12).

Enhancements in the optical properties of zirconia have resulted in significant improvements in its mechanical properties and long-term stability (13). Compared to other monolithic ceramics, monolithic zirconia veneers exhibit high bending and fracture strength (12). The advantage of monolithic zirconia lies in its machinability and the ability to apply paint before sintering, which makes it a faster and more cost-effective alternative to ceramic veneers. Depending on the sintering conditions, zirconia can achieve translucency while retaining its strength characteristics (14,15). Another benefit of monolithic zirconia over veneered types is the ability to prepare prostheses with reduced thickness, requiring only 0.5 mm of thickness for posterior teeth (16,17). By minimizing occlusal surface grinding of the underlying tooth, the tooth structure is preserved, providing adequate height for axial walls, thereby improving grip and veneer resistance (18). Advances in composition, microstructure, and manufacturing technology have resulted in stronger and more aesthetically pleasing veneers. However, certain clinical aspects, such as edge protrusion, still raise concerns (19). Spalling, which refers to small fractures in brittle materials, is a primary cause of clinical fracture in ceramics (19). Uneven stress distribution increases the risk of rebound. Small fractures can serve as initial stages of fracture, leading to veneer penetration, discoloration, and potential loss of the veneer's edge. This fracture process initiates from concentric contacts and propagates towards the free edge, forming subsurface fractures. In severe cases, replacement repair may be required for the patient (20). The stresses experienced at the margin area in the chamfer cut are higher compared to those at the shoulder. By increasing the stress distribution area at the edge of the shoulder, stress can be evenly distributed. In the shoulder margin, increasing the thickness of the coping reduces flexibility and decreases tensile stress in the porcelain structure (21). Hamper et al. conducted a study on the impact of thermocycling on edge flaking of restorative materials using a CAD-CAM system. The results of the study consistently showed a negative effect of erosion. All the samples exhibited sudden separation, resulting in a complete fracture pattern, which is typical of brittle materials. The closer the distance to the edge, the lower the fracture force required. Glass-ceramic samples displayed a lower force threshold for cracking compared to composites (22). Taufer et al. examined the edge chipping resistance of ceramics in glass ceramic IPS e.max CAD and monolithic zirconia (YZ-Zenostar Zr Translucent) samples. The study revealed that the force required for chipping increased with greater distance. Additionally, the force needed for edge jumping in monolithic zirconia samples was higher than in glass ceramic samples (19).

Tong et al. conducted a study on the edge spalling of highly translucent zirconia samples. The study reported two types of edge spacing: large and small. For small edge distances, the fracture strength increases as the distance decreases, despite having a lower fracture force. At small distances, the occurrence of edge spalling exceeds the fracture strength of ceramics. On the other hand, at large distances, the edge jump demonstrates the fracture strength typical of brittle solid materials (3). Johansson et al. compared the fracture rates of monolithic zirconia veneers and porcelain veneered frameworks. Two types of fractures were observed: overall fracture and fracture specific to the veneered layer. Monolithic veneers exhibited only overall fracture, whereas veneered veneers displayed both types of fracture. The results indicated that monolithic zirconia samples had higher fracture strength compared to veneered samples (21). Quinn et al. investigated the debonding of veneered zirconia and metal-ceramic veneers. According to their findings, buckling was not dependent on the type of infrastructure, and despite the different infrastructures of the coatings studied, the force required for edge buckling was not significantly different among them (1). To assess bounce, one method is performing the edge bounce test, which involves intentionally creating a jump in the material using a pen equipped with a load cell to measure the forces involved in the jump (1). With the growing utilization of monolithic zirconia restorations in dental implants, this study aims to compare the occurrence of edge spalling in implant-supported monolithic veneers with chamfered and shouldered margins.

Materials and method

Based on the research objective, previous studies (11), and considering a power of 80%, $\alpha = 0.05$, and s = 0.098, d = 0.098, a total sample size of 8 was determined, with 4 samples allocated to each group. Two premilled abutments from the dio system were selected and customized using abutment design software (Exocad). One abutment was given a shoulder margin, while the other had a chamfer margin. Subsequently, the abutments were prepared and scanned using the arumm machine. The software (Exocad) was used to design the veneer covers, and the coordinates for the veneers were transferred to the device. A total of 8 premolar veneers were fabricated on the two abutments for the 5 mm diameter implant. One abutment had a shoulder margin, while

the other had a chamfer margin. After scanning the data, the information was transferred to the CAD-CAM machine (Laserdenta, Germany). The veneer design was created using CAD software, ensuring complete anatomy of the maxillary left first premolar. The CAD-designed covers were then sent to CAM for machining. The coatings were prepared using the dry machining technique. Four veneers were fabricated on titanium abutments with a chamfered margin (1 mm deep). The anatomic veneers were machined using the CAD-CAM method, utilizing a LAVA CNC 500 m machining system and LAVA zirconia precenter blocks from 3M ESPE Dental Products, Seefeld, Germany.
The covers possess an average thickness of 1.5 mm, while an additional 4 veneers were crafted with a shoulder cut margin, reaching a depth of 1.3 mm. Following the machining process, the veneers need to undergo sintering and glazing using TABEO from NV Mihmvogt in Germany. The alignment and fit of the veneer margins on the abutment were carefully examined. The abutments were then screwed onto a stainless steel analog with a 5 mm diameter. This analog was positioned precisely within a PMMA block (Vertex Dental), with the distance from the highest part of the resin to the top of the replica implant measuring 3 mm. After air abrasion with 50-micron aluminum oxide, the abutments were placed on the replica using a torque of 30 newtons. The abutment screw was covered with cotton, and a temporary filling material (Cavit; 3M ESPE) was applied on top. Veneers were affixed to the abutment using temporary cement. To conduct the edge chipping test, a Vickers' pyramidal diamond pen was utilized, applying perpendicular pressure at a distance of 0.5 mm from the coating's edge. This process resulted in the creation of a depression on the surface and adjacent to the coating's edge.
Subsequently, the samples were subjected to compression using a metal piston with a 6 mm diameter in a universal testing machine (EMIC DL 2000, São José dos Pinhais, PR, Brazil). The compression was conducted at a speed of 0.1 mm/min until the first crack sound was detected, which was achieved by utilizing an amplified microphone connected to the testing machine. The sound waves were captured and recorded using specialized software (Audacity Sound Editor, Free Software Foundation, Boston, USA). The detection of the initial crack sound and the subsequent drop in the loading curve were documented. The cracked samples were then examined under light microscopy and transillumination with blue light to identify the initial crack and analyze fracture patterns. Statistical analysis and estimation of the Weibull modulus and critical fracture force with a 95% confidence level were performed using the Weibull distribution.
The collected data were entered into SPSS software version 26. Discrete data were presented as numbers and percentages, while continuous data were reported as mean and standard deviation. For normally distributed data, chi-square test was used to compare discrete variables, and t-test was employed for continuous variables. If the data distribution was not normal, non-parametric tests, such as the Mann-Whitney U test, were utilized. Regression analysis was employed to examine the relationship between variables. A significance level of $p < 0.05$ was considered statistically significant. Prior to participating in the study, informed consent was obtained from all participants, and throughout the entire research process, the patients' clinical information was kept confidential. Additionally, no costs were imposed on the patients for the imaging procedures.

Results
For this research, a total of 8 samples were prepared and compared. These samples were divided into two groups: chamfer (consisting of 4 samples) and shoulder (also consisting of 4 samples). Each group was subjected to a force of 30 Newtons. Table 1 displays the descriptive metrics for the variable of crack length, categorized by the two groups. The table indicates that the average crack length observed in the veneers based on implants with a chamfer margin (4.563) is greater than that of the shoulder margin group (0.481).

Table 1. Studying the descriptive indices of crack length by group

Crack length (µm)	Number	variation range	Min	Max	Mean	SD	Variance
Chamfer	9	179.8	454.6	634.4	563.4	58.9	3497.0
Shoulder	9	216	405.9	621.9	481.0	79.13	6261.9

According to Table 2, the average crack length in the chamfer group is 82.3 micrometers greater than that in the shoulder group. Furthermore, the 95% confidence interval for the difference in average crack length suggests that, with a 95% probability, the average crack length in the chamfer group is at least 5.12 µm higher and at most 152.0 µm higher than the shoulder group.

Table 2. Examining the difference of means for the crack length variable

	Mean differences	Mean standard error difference	95% confidence interval of the mean difference	
			Lower bound	Upper bound
Crack length (µm)	82.3	32.8	5.12	152.0

The outcomes of Levene's test, presented in Table 3, aim to assess the equality of variances in the crack length variable between the two groups. In Levene's test, the null hypothesis assumes that the variance of the variable under investigation is homogeneous across the groups. Based on the data in Table 3, since the P-value is less than 0.05, the assumption of homogeneity of variances is accepted. This assumption is crucial for utilizing parametric tests, including the independent t-test, allowing for further analysis using parametric methods.

Table 3. Levene’s test

Levene’s test	Degree of freedom 1	Degree of freedom 2	P-value
2.2	1	16	>0.05

The outcomes of the independent t-test for inferential analysis and comparison of the average crack length in the two groups are presented in Table 4. As indicated in Table 1, the average crack length in the chamfer group was observed to be higher than that in the shoulder group. Table 4 conducts an inferential analysis based on the descriptive results from Table 1. With a p-value less than 0.05, it can be concluded that there is a statistically significant difference in the average crack length between the chamfer group and the shoulder group.

Table 4. Independent t-test

t-statistic	Degree of freedom	P-value
2.5	16	>0.05

Table 5 provides descriptive statistics for the difficulty variable, categorized by two groups. The table demonstrates that the average hardness of veneers created using implants with a shoulder margin cutting (0.1739) is greater than that of the chamfer margin group (2.1554).

Table 5. Examining hardness indices of samples by group

Crack length (µm)	Number	variation range	Min	Max	Mean	SD	Variance
Chamfer	9	566	1402	1968	1554.2	187.7	35258.1
Shoulder	9	450	1502	1952	1739.0	177.3	31442.5

Table 6 displays that the hardness index in the chamfer group is, on average, 184.7 units lower than that in the shoulder group. Additionally, the 95% confidence interval for the difference in average hardness index indicates that, with a 95% probability, the average hardness index in the chamfer group is at least -2.367 units and at most -2.2 units lower than the shoulder group.

Table 6. Examining the mean hardness difference of the samples

	Mean differences	Mean standard error difference	95% confidence interval of the mean difference	
			Lower bound	Upper bound
Hardness of samples (kgf/mm^2)	-184.7	86.0	-367.0	-2.2

The results of Levene's test, presented in Table 7, aim to assess the homogeneity of variance in the difficulty variable between the two groups. Since the P-value is less than 0.05, it can be inferred that the variances in the two groups are similar. As a result, parametric tests are employed to compare the average hardness in the two groups.

Table 7. Levene's test

Levene's test	Degree of freedom 1	Degree of freedom 2	P-value
0.101	1	16	>0.05

The results of the independent t-test, presented in Table 8, serve the purpose of inferential analysis and comparison of the average difficulty between the two groups. As indicated in Table 5, the average hardness in the chamfer group was found to be lower than that in the shoulder group. Table 8-4 conducts an inferential analysis based on the descriptive results from Table 5. With a p-value less than 0.05, it can be concluded that there is a statistically significant difference in the average hardness between the chamfer group and the shoulder group.

Table 8. Independent t-test

t-statistic	Degree of freedom	P-value
-2.1	16	>0.05

The crack length measured in all samples was 551.025 ± 74.8 mm. There was no statistically significant distinction observed in the average crack length between the two groups, as indicated in Table 9.

Table 9. Comparison of the crack length created in two groups

Sample	***Mean crack length (mm)***	***SD***	***P-Value***
Chamfer	*563.825*	*76.7*	*0.8*
Shoulder	*538.225*	*82.1*	

The length of cracks created in both groups are shown in pictures (1 and 2).

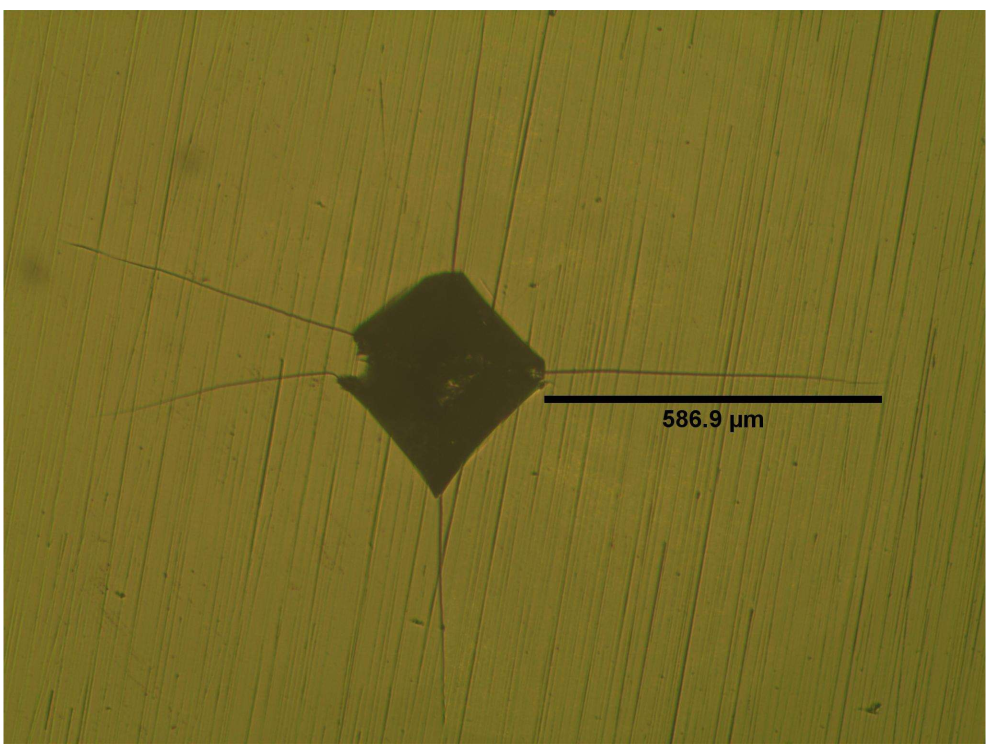

Figure 1. The crack created in the chamfer lathe

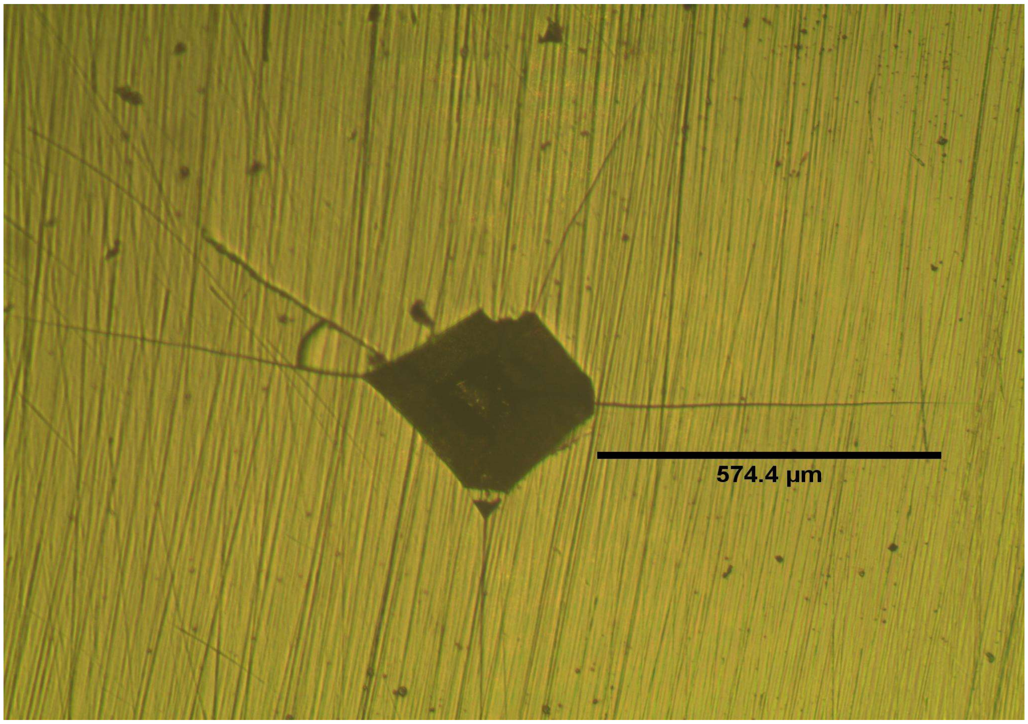

Figure 2. The crack created in the shoulder lathe

Discussion

The findings of the current study indicate that shoulder lathes exhibit significantly higher strength than chamfer lathes. These results align with a previous study conducted by Beuer et al., which investigated the fracture resistance of zirconia blinds and similarly found that the shoulder margin exhibited superior biomechanical properties (23). Considering that the fracture resistance in both groups exceeds the forces typically encountered within the oral cavity, both cutting designs can be effectively utilized for PFM veneers and serve as viable alternatives.

Multiple factors may contribute to the enhanced fracture resistance of monolithic zirconia veneers. Schillingberg proposed that the radial shoulder, as opposed to the 90° shoulder, is advantageous for all-ceramic restorations due to the elimination of internal sharp angles, leading to reduced stress concentration within the tooth and veneer (24). In two other studies, Jalalian et al. observed that the chamfer design exhibited greater resistance than the shoulder design in zirconia veneers and increams. They attributed this difference to the rounded internal angle, improved force distribution, and the better fit of the marginal chamfer compared to the 90-degree shoulder. Furthermore, a finite element study on monolithic zirconia crowns reported that a chamfered or rounded cutting design could enhance the mechanical performance of posterior single-unit zirconia crowns (25).

In a separate study conducted by Jalalian et al. in 2020, it was demonstrated that the fracture resistance of the chamfer group is significantly superior to that of the shoulder group (26). The presence of a slope in the chamfer margin and a better marginal fit can be considered as influential factors contributing to this difference. Another study discussing the presence of a "bull" reported that margins with a bull are more suitable, resulting in a smaller vertical distance between the veneer and the cutting margin (24). A similar interpretation can be applied to the chamfer design, as it includes a slope that reduces the vertical distance between the veneer and the margin by 90 degrees compared to the shoulder design. Consequently, a better marginal fit and more even distribution of forces are achieved, leading to higher fracture resistance in the chamfer group's monolithic zirconia veneers.

In a study conducted by Gungor et al. on the fracture resistance of zirconia blinds, it was discovered that a 135-degree shoulder margin exhibited superior biomechanical properties compared to a 90-degree shoulder. Other studies suggest that a 90-degree shoulder margin is necessary for porcelain to withstand occlusal forces. However, this hypothesis appears to be based on studies conducted on ceramics with lower strength, such as feldspathic ceramics. Increasing the strength of ceramics, particularly in the case of zirconia, may mitigate the impact of cutting design in ceramic applications (24, 27).

In a separate study conducted by Marit Øilo et al., the impact of crown margin preparation and design on fracture resistance was investigated. The study's findings revealed that chamfer veneers exhibited higher resistance to fracture compared to slice preparation veneers. Furthermore, the inclusion of an additional cervical collar increased the load at fracture for hard machined crowns (28). This result may be attributed to the increased thickness at the crown's edge. However, thicker crown walls may pose a risk to tooth longevity due to the need for increased drilling depth (18, 29-30). These findings align with previous studies demonstrating that increasing the border thickness in the cervical area enhances fracture resistance in chamfer blade designs relative to other blade designs (31-33). On the other hand, excessively contoured crown margins could compromise gingival and periodontal health. Thus, the study suggests that modified crown designs with incision preparation may contribute to improved technical and biological success. Moreover, it has been demonstrated that reducing occlusal thickness results in weaker crowns, potentially exerting a greater influence on fracture resistance than cervical thickness (34). Additionally, veneered veneers have exhibited significantly lower fracture resistance, indicating that zirconia post-treatments have a negative impact on fracture strength (35, 36).

Conclusion

Since both lathe designs exhibit a remarkably high resistance to fracture, surpassing the forces encountered within the oral cavity, it can be inferred that both cutting designs are suitable for clinical use.

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