FRACTURE LOAD AND FAILURE MODES OF ZIRCONIA CROWNS ACCORDING TO FINISH LINES AND FRAMEWORK DESIGNS

Stafford S. U.[1]**, Ulusoy M.**[2]**, Türk A. G.**[2]*

[1] Private Practice, Bristol, United Kingdom
[2] Department of Prosthodontics, Ege University School of Dentistry, Bornova, Izmir, Turkey.

Corresponding author: Ayse Gozde Turk, Associate Professor, Department of Prosthodontics, Ege University School of Dentistry, Bornova, Izmir, Turkey.
Correspondence: ayse.gozde.turk@ege.edu.tr

DOI: https://dx.doi.org/10.4314/gdj.v22i2.9

ABSTRACT

AIM: This study aimed to assess the fracture load of bilayered zirconia crowns with varying finish lines and framework designs.

METHODS: Three prefabricated mandibular right first molar teeth were prepared with distinct finish line designs: shoulder (S), Chamfer (C), and feather-edge (F). Each group was duplicated onto 22 cobalt-chromium dies. Zirconia copings were fabricated with either anatomic or non-anatomic framework designs, veneered, and then cemented using adhesive resin cement. All specimens underwent thermocycling and mechanical ageing. Fracture load testing was performed using a universal testing machine, and failure modes were analyzed using stereomicroscopy and scanning electron microscopy (SEM).

RESULTS: The type of finish line significantly influenced the fracture load of zirconia crowns ($p < 0.05$), with the chamfer group exhibiting the highest mean fracture load. However, no significant difference was observed between the shoulder and feather-edge groups ($p > 0.05$). Framework design (anatomic vs. non-anatomic) had no statistically significant effect on fracture load ($p > 0.05$). Most failures were cohesive, especially in the feather-edge group. Group C had a significantly greater fracture load value compared to the other groups ($p < 0.05$). However, the clinically recommended S and minimally invasive F groups had similar fracture loads ($p> 0.05$). The framework design did not significantly affect the fracture load.

CONCLUSION: The chamfer finish lines achieved the highest fracture load for bilayered zirconia crowns, while minimally invasive knife edge finish lines were mechanically strong enough for clinical use. Although the vertical finish line involved less tissue destruction, it raises some concerns about failure.

KEYWORDS: Zirconia Crowns, Fracture, Coping Design, Dental, Restorations, Failure Modes, Finish Lines

INTRODUCTION

Recent developments in dental materials have greatly impacted restorative dentistry, such as zirconia, which is currently the preferred material for fixed prostheses. Zirconia is a polycrystalline ceramic with high strength and fracture toughness[1]. Its tetragonal structure uses a special transformation-toughening process to increase fracture toughness. Stress concentration stops a fracture from growing further by transforming tetragonal crystals into monoclinic crystals as it expands[2]. Due to this, zirconia restorations can withstand masticatory pressures more effectively than other ceramic restorations.

Recently, zirconia-based crowns have gained popularity due to their high mechanical, aesthetic, and excellent biocompatibility properties[3]. It is preferred for anterior and posterior restorations due to its aesthetic, durability, and masticatory strength in fixed prostheses. The framework designs influence mechanical performance in preparation and the choice of finish lines in a zirconia crown[4]. Recently, feather-edge margins have been used due to the trend in minimally invasive dentistry, although traditional shoulder and chamfer designs are also widely applied. Patient demographics and preferences[6] may also influence the use of zirconia crowns.

Recent research has shown an association between minimally invasive techniques and the preservation of dental hard tissue and pulp vitality, sparking interest in finish-line design research for zirconia crowns[7]. The finish lines of tooth preparation margins are the factors that determine the restoration's mechanics and aesthetics. Traditionally, horizontal finish lines, such as shoulders and Chamfers, have been recommended for zirconia restorations due to their efficient stress transfer and low risk of chipping[9]. However, better mechanical properties of zirconia offer the possibility of minimal invasiveness with vertical preparations that may feature feather-edge margins, promoting tooth preservation and aesthetics.

Clinical results demonstrate that crowns made from zirconia copings have a high success rate. A recent systematic review reported a success rate of 73.9% to 100% with zirconia-based prostheses[10]. The only side effect is minor chipping of the veneering ceramic, especially within the molar regions. It is due to the thermal conductivity, coefficient of thermal expansion between the core and veneer materials, flexural strength, bond strength between the coping and ceramic, and thermal stress during the firing of the ceramic. Several factors influence the fracture evolution of all-ceramic crowns, including marginal design, framework design, coping thickness, and the type of luting agent; however, their individual contributions remain a subject of investigation.

Despite extensive research on zirconia crowns, a comparative analysis to assess the influence of different finish line designs and framework configurations on the fracture load of restorations is still lacking. Practically all reported fracture loads for zirconia crowns fall within the range of 368.3 N to 712 N, which, again, is due to processing variability and design parameter sensitivity, indicating variance[7]. Several parameters, including coping thickness, marginal design, and luting agent, are known to affect the mechanical performance of zirconia crowns; however, reports on the contribution of the finish line and framework design to this relationship are lacking. Although prior studies have reported that finish line and framework designs influence fracture resistance, the comparative performance of specific types of finish lines and framework designs under standardized laboratory conditions remains insufficiently understood[11]. Therefore, the current study investigates whether these design variations yield statistically significant differences in fracture load.

It compares the influence of various finish lines and framework designs on the fracture resistance of zirconia crowns. It investigates the fracture load properties of bi-layered zirconia crowns with different types of finish lines, i.e., shoulder, chamfer, or feather-edge, and framework designs, either anatomic or non-anatomic. Findings will provide more information that clinicians can factor into crown design decisions, particularly regarding the preservation of tooth structure. This study aims to determine which finish line design is most effective with respect to optimal fracture resistance.

MATERIALS AND METHOD

Study Design

A controlled laboratory experimental design was employed to assess the mechanical performance of bilayered zirconia crowns that differ in various finish lines and framework designs. Emphasis was placed on evaluating fracture load under standardized conditions that simulate the clinical situation as closely as possible. For the experiment, the researcher obtained crowns designed differently and subjected them to specific thermal and mechanical aging procedures, simulating prolonged use in the oral environment. Thermocycling was employed to simulate the thermal stresses induced by the consumption of hot and cold foods and beverages, which can lead to material fatigue and microcrack propagation. All specimens were subjected to 10,000 thermal cycles alternated between two temperatures, a cold bath (5 °C) and a Hot bath (55 °C), for 30 seconds each. Cyclic Mechanical Preloading was performed using a chewing simulator to replicate the repetitive forces generated during chewing and parafunctional habits such as bruxism, which can gradually degrade material integrity over time. It provided a controlled setting through which the fracture load and failure modes were measured and analyzed, thus contributing to the reliability of the results.

Study Location or Setting

The study was conducted at Ege University School of Dentistry, Bornova, Izmir, Turkey. This academic institution offers an extensive range of dental materials, modern equipment installed in state-of-the-art laboratories, and faculty members with extensive experience in prosthodontics. The environment provided a suitable setting for conducting systematic tests of the zirconia crowns, ensuring that all necessary protocols were followed during preparation, testing, and analysis. The investigator had access to the necessary equipment, which consisted of a stereomicroscope and a scanning electron microscope, for examining failure modes and fracture characteristics.

Sample Size of the Study

The study used a sample size of 66 cobalt-chromium dies, which were divided into three different finish line designs: shoulder (S), Chamfer (C), and feather-edge (F). To ensure that the prepared crown baselines were consistent, three prefabricated mandibular right first molar teeth were used. This sufficient sample size allowed for the achievement of proper statistical power for comparison, ensuring the reliability of the results.
Prefabricated mandibular right first molar teeth without any previous restorations or structural anomalies were selected to ensure uniform preparation and baseline comparability. Teeth were suitable for standardized shoulder, chamfer, or feather-edge finish line preparations were used for the study. Duplicated cobalt-chromium dies were accepted only after visual and dimensional inspection to ensure defect-free replication of finish lines and anatomical features.
Teeth exhibiting pre-existing restorations, caries, or anatomical deformities were excluded.
Duplicated dies with visible casting defects, marginal distortion, or surface irregularities were discarded. Crowns exhibiting internal voids, marginal misfits, or veneering defects (cracks, chipping) upon inspection were not included for cementation.

Experimental Procedure

Three artificial typodont mandibular right first molars were mounted in acrylic resin with the cementoenamel junction at 3 mm above the acrylic. An impression was taken to standardize the crown size, and the crown was reduced accordingly. Specimens were divided into three groups based on finish lines: Chamfer, shoulder, and feather-edge with specific preparation measurements. Silicone impressions were taken using the lost-wax technique to produce cobalt-chromium dies.
Zirconia copings were designed and milled with a marginal gap of 20 µm and thickness of 0.7 mm. They were finally sintered to acquire the hardness. Veneering ceramic was applied and fired onto the zirconia copings according to the manufacturer's instructions. Prior to cementation, the inner surfaces of the crowns were air-abraded (typically with aluminum oxide) to enhance micromechanical retention. The crowns were then cemented onto the cobalt-chromium dies using Panavia F 2.0, a dual-cure resin cement. After seating the crowns, a standardized vertical load was applied for 10 minutes to ensure complete seating and uniform cement thickness during the initial polymerization phase.
Samples were aged in distilled water for 24 hours and then subjected to thermocycling. Subsequently, cyclic preloading was applied by altering forces. Compressive axial load was provided until fracture occurred. All the fracture loads were evaluated, and broken samples were microscopically examined to classify the fracture type. The representative samples were subjected to fractographic analysis using scanning electron microscopy to verify the fracture characteristics. Fracture load testing was performed using a universal testing machine equipped with a stainless steel piston of 5 mm diameter. A three-point contact configuration was established between the flat piston tip and the functional cusps of each crown to simulate natural occlusal loading.
Zirconia copings were designed in two distinct framework configurations: anatomic, which followed the natural tooth morphology and allowed for uniform veneering thickness, and non-anatomic, which incorporated a simplified coping design with a bulkier central support area.
Each finish line group (shoulder, chamfer, feather-edge) consisted of 22 specimens, which were equally divided into 11 anatomic and 11 non-anatomic subgroups, resulting in six experimental subgroups:

1. Chamfer Anatomic (CA), Chamfer Non-Anatomic (CN)
2. Shoulder Anatomic (SA), Shoulder Non-Anatomic (SN)
3. Feather-edge Anatomic (FA), Feather-edge Non-Anatomic (FN)

This distribution enabled the comparison of framework designs within each finish line category.

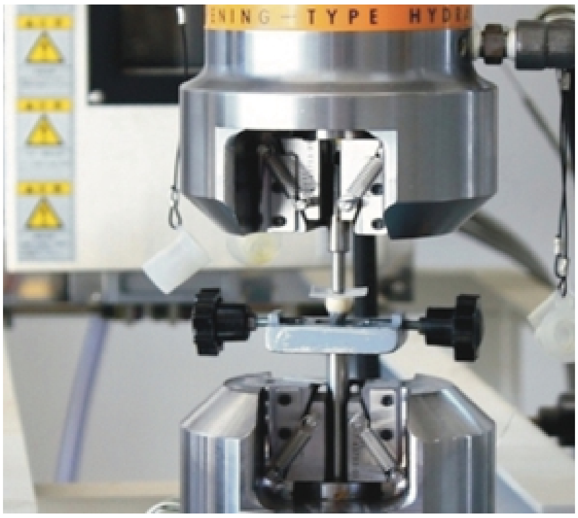

Figure 1. Load Testing Procedure

Figure 1 shows a load testing procedure for a zirconia crown. The crown, cemented onto a cobalt-chromium die, was pressed between two jaws and then firmly placed in the holder, simulating the real situation in which it would adhere to the tooth. It is then subjected to a gradually increasing vertical load until the breaking point is reached to determine the strength and stress resilience of the crown under simulated biting conditions.

Data Collection

The study collected both quantitative and qualitative data related to the mechanical performance of zirconia crowns. Data were gathered systematically at multiple stages of the experimental protocol:

1. Fracture Load: For each specimen, quantitative data of the maximum load at failure (in Newtons) was recorded using a universal testing machine. This was the primary outcome variable used to assess mechanical strength.
2. Failure Mode Classification: After fracture testing, each specimen was visually inspected using a stereomicroscope to determine the mode of failure, classified as adhesive, cohesive, or total, which was qualitative data. A subset of fractured specimens was further examined under scanning electron microscopy (SEM) to verify the crack origin, propagation path, and material interface characteristics.
3. Coping Design Verification: Qualitative data for each coping was documented as either anatomic or non-anatomic and cross-verified before veneering to ensure conformity with the experimental subgroup assignment.
4. Preparation and Cementation Parameters: Details such as marginal gap design (20 μm), coping thickness (0.7 mm), cement type (Panavia F 2.0), and curing duration were standardized and recorded during fabrication and seating stages to ensure reproducibility.

Data Analysis

The study employed various statistical methods to analyze the data, including failure testing using stereomicroscopes and scanning electron microscopy to investigate fracture propagation and failure mechanisms. Unpaired sample t-tests were used to determine differences in fracture loads between anatomic and non-anatomic subgroups, while one-way ANOVA was used to assess differences between the three finish line designs. The Duncan multiple range test was used to establish significant differences within groups at $p > 0.05$. The data were analyzed using SPSS software (version 15.0). Statistical analyses included Levene's test for homogeneity of variances, independent (unpaired) t-tests for comparison between two groups, one-way analysis of variance (ANOVA) for comparing multiple groups, the Duncan multiple range test for post-hoc pairwise comparisons, and the Chi-square test for analyzing categorical data. The level of significance was set at $p > 0.05$.

RESULTS

Table 1 presents the mean, standard deviation, minimum, and maximum fracture loads of six groups of zirconia crowns with regard to various finish lines and framework designs. Chamfer anatomic (CA) crowns had the highest mean fracture load at 4472.91 N, ranging from 1684.38 N to 6656.25 N, although this difference was not statistically significant ($p > 0.05$). The mean of chamfer non-anatomic (CN) was 3576.14 N and fracture loads in feather-edge anatomic (FA) and shoulder non-anatomic (SN) were scattered. The data did not show any obvious difference between groups (p-values > 0.150).

Table 1. Mean, standard deviation, minimum, and maximum values of fracture load for finish line and framework groups

Group	Mean (N)	Standard deviation (SD)	Minimum (N)	Maximum (N)	P Value
CA (control)	4472.91	1571.77	1684.38	6656.25	0.15
CN	3576,14	1092.44	1015.63	5193.75	
SA	2494.69	821.07	1231.25	3387.5	0.311
SN	3154.26	1893.95	1237.5	7603.13	
FA	3270.74	1294.81	1959.38	6512.5	0.324
FN	2666.47	1498.84	878.12	6259.38	

(CA: chamfer anatomic, CN: Chamfer non-anatomic, SA: shoulder anatomic, SN: shoulder non-anatomic, FA: feather-edge anatomic, FN: feather-edge non-anatomic)

Table 2 presents a comparison of fracture loads among different zirconia crowns with various types of finish lines. Crowns with the chamfer (C) finish line demonstrated the highest mean fracture load at 4016.48 N and were thus significantly stronger than those in the shoulder and feather-edge groups, which had $p < 0.05$. The shoulder and feather-edge crowns were lower in mean fracture loads (2876.32 N and 2968.61 N, respectively), and there was no statistically significant difference between these two groups as indicated by the same superscript letter "b." The chamfer group demonstrated the minimum value but showed overall higher fracture resistance.

Table 2. Mean, standard deviation, minimum and maximum values of fracture load for each finish line (different superscript letters show statistically significant difference among groups), p < 0.05

Groups	Mean (N)	Standard Deviation	Minimum (N)	Maximum (N)
C	4016.48	1308.88^{a}	1015.63	6656.25
S	2876.32	1413.04^{b}	1231.25	7603.13
F	2968.61	1401.34^{b}	878.125	6512.50

(C: Chamfer, S: shoulder, F: feather-edge)

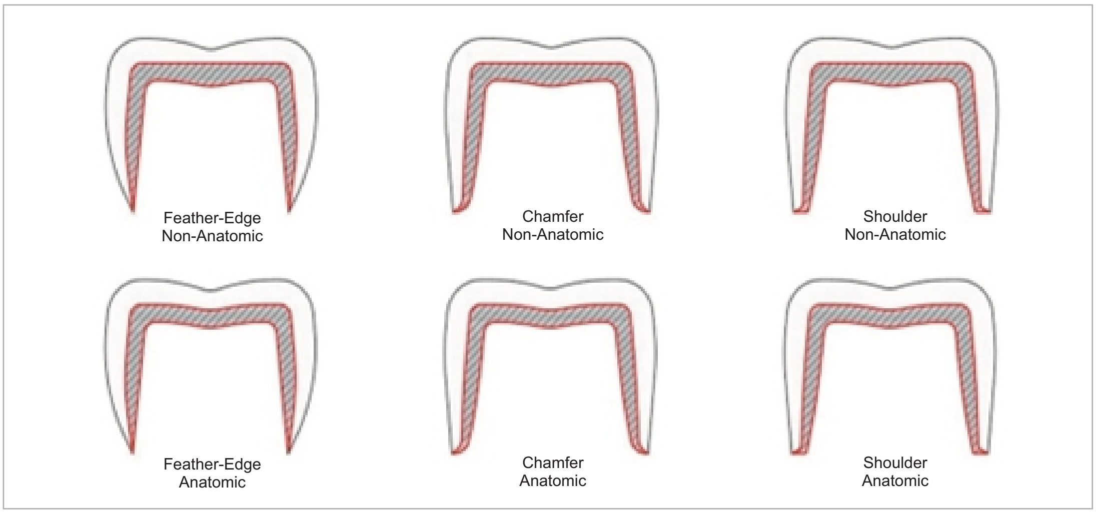

Figure 2. Finish Lines and Framework Designs

Figure 2 differentiates the varieties of finish lines and frameworks pertaining to dental restorations. The upper row includes non-anatomic designs, such as feather-edge, chamfer, and shoulder, while the bottom row is anatomic designs. Feather-edge preparations depict a sharp, knife-like edge, while chamfers are bevelled edges with shoulders that display an egg-shaped outline. Anatomic designs replicate the natural shape of the teeth, providing a more aesthetically pleasing view. The position of the finishing line and the framework design can be changed based on the type of restoration being made, tooth anatomy, and patient preference.

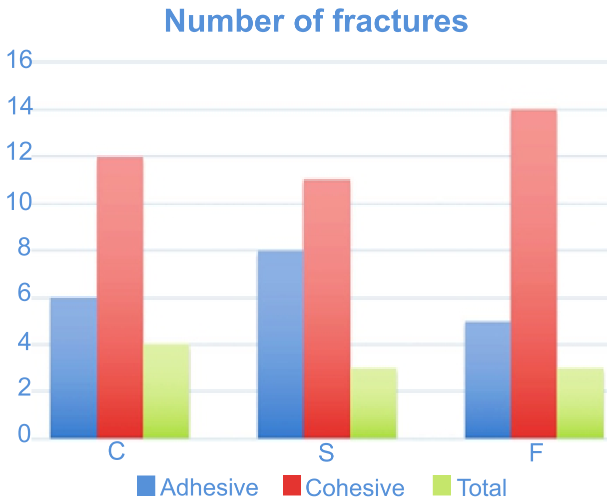

Figure 3. Frequency of the Fracture Types for Groups C, S, and F

Figure 3 illustrates three types of fractures: adhesive, cohesive, and the total number of fractures for groups C, S, and F. From the graph; it can be seen that group F has the highest total number of fractures, followed by group S, and then group C. In addition, each group showed a different distribution of fractures, with group F having the highest percentage of cohesive fractures compared to the other groups.

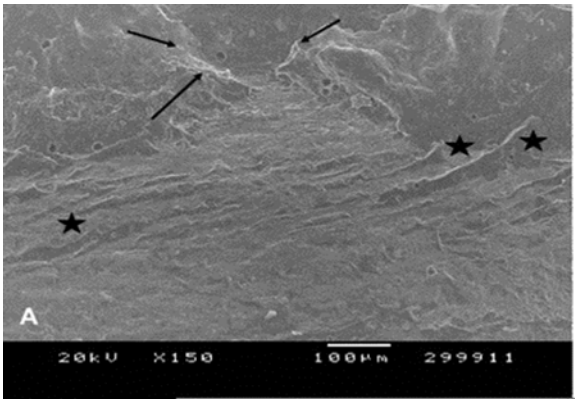

Figure 4A. Scanning electron microscopy (SEM) image of adhesive fractures, with arrows marking the crack origin and stars indicating porcelain remnants on the zirconia core

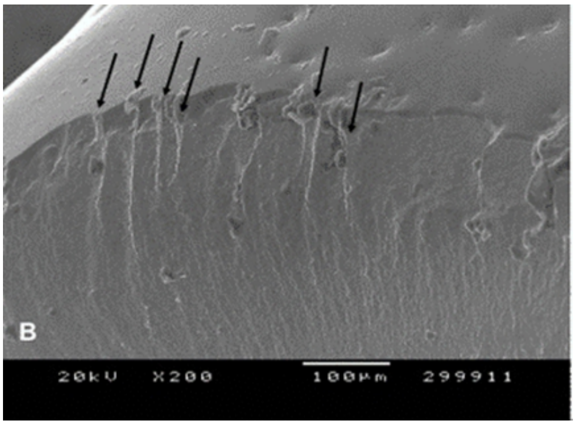

Figure 4B. Scanning electron microscopy (SEM) image of total fracture, with arrows indicating the direction of crack propagation.

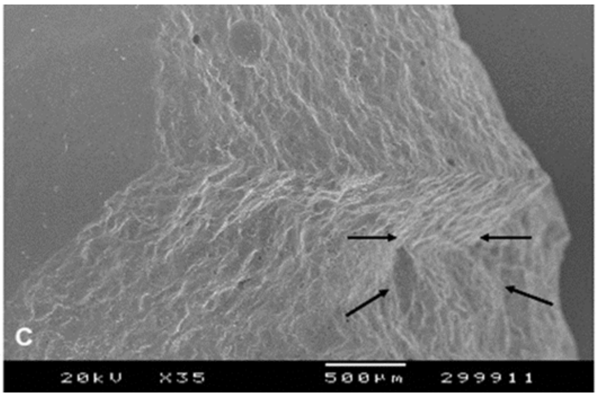

Figure 4C. Scanning electron microscopy (SEM) image of cohesive fracture, highlighting the crack origin with arrows

Figure 4 shows scanning electron microscope (SEM) images of the different fracture types in zirconia restorations. Figure 4A shows an adhesive fracture type; the fracture crack initiation is at the porcelain and zirconia core interface with remnants of porcelain on the zirconia core. Whereas Figure 4B shows the total fracture type, the fracture crack propagates entirely through both porcelain and zirconia. Additionally, Figure 4C shows a cohering fracture where the crack occurs within the material, the zirconia. These images help explain, in part, the failure mechanisms of zirconia restorations, providing researchers and clinicians with insight into why these restorations fail.

DISCUSSION

Important statistical insights were revealed by analyzing the fracture loads of zirconia crowns with different finishing lines and framework designs. According to the results, chamfer anatomic crowns had a mean fracture load of 4472.91 N (SD: 1571.77, range: 1684.38–6656.25), which was not significantly different from the other groups ($p > 0.05$). The mean value for the chamfer non-anatomic crowns was 3576.14 N. Among the finishing lines, Chamfer (C) crowns had distinctly higher strength at 4016.48 N (SD: 1308.88, range: 1015.63–6656.25) and thus, were stronger than shoulder (S) and feather-edge (F) crowns whose mean loads were 2876.32 N (SD: 1413.04) and 2968.61 N (SD: 1401.34), respectively, (both $p < 0.05$). Feather-edge crowns exhibited the most significant total number of fractures, mostly cohesive, according to fracture analysis, and SEM pictures revealed the causes behind zirconia restoration failure.

From the results of our study, the fracture load of zirconia molar crowns is influenced by the finishing line. Thus, our hypothesis was partially accepted. Such an outcome is consistent with earlier studies on this topic[7,12,13]. As previously mentioned, it has been stated that all ceramic restorations must be placed on either a chamfer or a rounded shoulder preparation so that they can withstand the stresses and are reported to transfer the minimum amount of masticatory stress from the coping to the veneering ceramic.[14,15] They are reported to transfer the minimum amount of masticatory stress from the coping to the veneering ceramic[16]. Findakly & Jasim (2019) concluded that zirconia crowns at shoulder preparation type have higher fracture loads than feather-edge finishing line 12. A clinical study of zirconia crowns demonstrated that there were no differences in survival and success rates between feather-edge and chamfer finishing lines at 4 years17. Other studies have found greater strength when crowns are made of zirconium oxide with a 0.5-mm knife-edge finish line compared to crowns with a chamfer finishing line[7,18].

A significant amount of the tooth structure must be removed to achieve rounded shoulder and chamfer finish lines. A minimally invasive approach is crucial for preserving the health of pulp tissue and remaining tooth structures. It has been reported that 8–15% of formerly vital teeth required endodontic treatment after a chamfer finish line.[19-21] In contrast, more conservative preparations, such as a feather-edge finish line, allow the clinician to preserve the maximum amount of healthy tissue. It is stated that zirconia-reinforced glass ceramic and monolithic zirconia crowns can be prepared with non-invasive finishing lines.[22] Recent clinical studies have shown that the feather-edge preparation type presents better gingival health, marginal stability, good oral hygiene, and esthetics with zirconia crowns.[23-25] Feather edges are especially essential for periodontally involved teeth as abutments for fixed prosthesis, endodontically treated teeth, vital teeth in young people, and those which are affected by caries at the cervical third of the clinical crown [17,26], lingual surfaces of mandibular posterior teeth, convex axial surface and inclined tooth surfaces [27].

In our study, the feather-edge group did not differ significantly from the clinically advised shoulder group. Based on these results, the feather-edge group is mechanically feasible and suitable for zirconia molar crowns. According to the study by Beuer et al. (2008), this favourable outcome of feather-edge preparation can be attributed to the pattern of stress developed during loading[12]. The load on the coping increased, allowing it to slide down the axial wall of the die without being limited by the margin. That was followed by a concentration of stress on the occlusal surface of the coping. Although the feather-edge preparation was successful, the authors claimed it was obsolete from a periodontal perspective. However, histological evidence also exists showing no difference in periodontal health among different finish lines[28]. Furthermore, existing recommendations to avoid vertical preparations were not supported by clinical studies due to the performance of the restorations [29].

Additionally, in the present study, the anatomic and non-anatomic core designs yielded similar fracture loads. When an anatomic core design was tested, a porcelain layer with an even thickness could be obtained. It is known that an optimized zirconia structure design with increased occlusal support and a veneering ceramic with even thickness reduces the number and surface area of chipping incidents[30]. However, in our study, increased core thickness in the central pit region of the non-anatomic cores, where stress was concentrated, supported the brittle porcelain layer, which may have led to similar fracture loads for crowns with anatomic core designs. This may compensate for the advantages and disadvantages of the core design; thus, the anatomic and non-anatomic designs showed no statistically significant differences.

The clinical ceramic crown does not have any set method for testing its compressive strength. Its effect could be observed in various types, such as finishing lines, core designs, ceramic material, crown thickness, method of luting, cyclic preload, thermocycling, loading condition, and the elastic modulus of the supporting die.[31,32] The literature indicates that the fracture load increases with an increase in the elastic modulus of the material used for support.[33] The supporting Co-Cr die had an elastic modulus of 200 GPa, which is much greater than that of dentin at 12 GPa. It would be even lower in the case of a natural tooth, acrylic resin, or a composite resin used as a supporting model. However, the destruction of natural teeth or acrylic resin due to high fracture loads, as cited in the literature, would have been avoided.[34] In this study, metal dies were taken into consideration to withstand higher fracture loads without getting destroyed. The groups were compared without data loss, unlike earlier in vitro studies, which found the destruction of disease [33, 35]. Moreover, this method ensured the standardized reproduction of all dies. Therefore, the outcome for all groups under examination can be rightly compared. However, there are still limitations to in vitro studies, so the results must be interpreted cautiously.

It has been shown that masticatory loads range from 50–250 N, while parafunctional behaviours, including bruxism, can generate loads between 500–1000 N [36]. All groups evaluated in this study showed greater failure loads than the maximum chewing forces. Thus, all test specimens exceeded the limits of fracture resistance for posterior restorations, as confirmed by previous in vitro studies [33, 37]. Based on the investigated fracture load, bi-layered zirconia molar crowns exhibited a failure strength ranging from 2598.37 N to 4456.82 N.

Previous studies using similar pre-testing procedures have concluded that artificial ageing by preload and thermocycling can have a significant effect on ceramic materials [38,39]. In the present study, dynamic cyclic loading was combined with thermocycling to simulate the ageing of the specimens. The rapid change in temperature when the restorations are submerged in baths could create stresses in the specimens between the surface and the bulk material. When tension and compression periodically occur at a crack tip due to load cycles, the damage is exacerbated by the presence of water. Hence, small defects introduced during the fabrication process may have a detrimental effect on the fatigue life of zirconia restorations. The number of thermocycles and cyclic loads in the present study was set to 10,000 cycles, based on previous studies. Cyclic loads were performed with a crosshead speed of 1 Hz.[40, 41]

One of the common evaluation techniques for mechanical properties is a one-cycle load-to-failure (static compression) test method, particularly applied to the loaded specimens [42]. The tests with fracture load subject the specimens to very high stresses, much higher than maximum chewing forces, and thus lead to controlled failure at the site of stress concentration. These tests involve loading specimens under controlled laboratory conditions, thereby gaining a better understanding of the variables under investigation. The direction and location of the load application must be considered to simulate functional loading during mastication. This would place a silicon sheet between the loading indenter and the restoration to prevent cracking the cone and mimic the cushioning effect that food can play when placed between opposing teeth [34, 43.]

The diameter of the loading piston affects the fracture load.[44] In the current study, the diameter was considered comparable to that in similar research works, allowing for a three-point contact between the piston and the occlusal surface of the specimen. All these specimens were cemented with the same loading conditions. Additionally, the results may have been influenced by the adhesive luting agent [45]. After adhesive luting, all ceramic crowns exhibited higher fracture resistance compared to conventional cement[46].

The hand layering technique was used in this study because it is the most preferred technique among laboratory technicians. When comparing the fatigue of veneered and heat-pressed zirconia crown systems, no statistical difference was found between the two techniques [47]. Therefore, the results of this study should be compared with other veneering techniques used in other studies. In this in vitro study, artificial acrylic teeth and CAD/CAM technologies allowed for the manufacturing of molar crowns of identical size and shape. Such uniformity is important for a reliable comparison of different groups and may allow for identifying single risk factors [48].

Bi-layered zirconia crowns generally exhibited cohesive fractures, and adhesive fractures were rare, as reported in recent studies.[49] Cohesive fractures indicate that there was a good interfacial bond between the core and the veneer material, which is critical for the success of the composite structures. Also, this study showed that failure modes were not different from coping design, as stated in the study by Ramos et al. (2015)[50].

The design of in vitro studies has some inherent limitations, which make it difficult to compare results with clinical situations. One major limitation of the current study was that the fracture load of the restorations was evaluated under static loading after undergoing thermocycling and cyclic loading procedures. In reality, restorations are exposed to saliva, which is a dynamic fluid with a complex mixture of organic and inorganic components. Therefore, the test procedures should employ stress corrosion or corrosion fatigue to provide an accurate forecast of long-term restoration performance.[51]

CONCLUSION

The study found that single zirconia crowns did not alter fracture load regardless of whether the framework design was anatomic or non-anatomic. The highest fracture load was achieved with a chamfer finish line for bilayered zirconia crowns; however, clinically recommended shoulder and minimally invasive feather-edge finish lines had similar fracture loads. Less invasive finish-line options may be preferred in certain indications, but more clinical studies are needed before recommendations can be made.

RECOMMENDATIONS

Future research should investigate the long-term stability of minimally invasive finish lines, the impact of cementation techniques, and the effects of various occlusal loads on the fracture resistance and failure modes of zirconia crowns.

REFERENCES

1. Vitti, R.P., et al., Zirconium in dentistry, in Advanced Dental Biomaterials. 2019, Elsevier. p. 317-345.

2. Zhao, T., J. Zhu, and J. Luo, Study of crack propagation behavior in single crystalline tetragonal zirconia with the phase field method. Engineering Fracture Mechanics, 2016. 159: p. 155-173.

3. Huang, B., et al., Advances in Zirconia-Based Dental Materials: Properties, Classification, Applications, and Future Prospects. Journal of Dentistry, 2024: p. 105111.

4. Haggag, K., M. Abbas, and H. Ramadan, Effect of thermo-mechanical aging on the marginal fit of two types of monolithic zirconia crowns with two finish line designs. Al-Azhar Dental Journal for Girls, 2018. 5(1): p. 121-128.

5. Yu, H., et al., Minimal invasive microscopic tooth preparation in esthetic restoration: a specialist consensus. International Journal of oral science, 2019. 11(3): p. 31.

6. Merli, M., et al., Ceramic vs composite veneering of full arch implant-supported zirconium frameworks: assessing patient preference and satisfaction. A crossover double-blind randomised controlled trial. European Journal of Oral Implantology, 2017. 10(3).

7. Ardakani, Z.H., et al., The effect of finish line design on the fracture strength of zirconia copings. Journal of Dentistry, 2019. 20(4): p. 271.

8. Field, J., J. Steele, and R. Wassell, Fundamentals of tooth preparation. Extra-Coronal Restorations: Concepts and Clinical Application, 2019: p. 329-362.

9. Basem, F.A., Vertical tooth preparation in crown and bridge. 2022, University of Baghdad.

10. Nejatidanesh, F., et al., Five year clinical outcomes of metal ceramic and zirconia-based implant-supported dental prostheses: A retrospective study. Journal of Dentistry, 2020. 100: p. 103420.

11. Badran, N., S. Abdel Kader, and F. Alabbassy, Effect of Incisal Porcelain Veneering Thickness on the Fracture Resistance of CAD/CAM Zirconia All-Ceramic Anterior Crowns. International Journal of dentistry, 2019. 2019(1): p. 6548519.

12. Findakly, M.B. and H.H. Jasim, Influence of preparation design on fracture resistance of different monolithic zirconia crowns: A comparative study. The Journal of advanced prosthodontics, 2019. 11(6): p. 324-330.

13. Oyar, P. and R. Durkan, Effect of cavity design on the fracture resistance of zirconia onlay ceramics. Nigerian Journal of clinical practice, 2018. 21(6): p. 687-691.

14. Emam, M., A. El-Etreby, and J.F. Younis, Fracture resistance and strain analysis of zirconia copings with vertical knife edge and three horizontal finish line designs; chamfer, deep chamfer and shoulder with two cementation techniques. Brazilian Dental Science, 2021. 24(4).

15. Euán, R., et al., comparison of the marginal adaptation of zirconium dioxide crowns in preparations with two different finish lines. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry, 2012. 21(4): p. 291-295.

16. Alp, Ş., L. Gulec Alagoz, and N. Ulusoy, Effect of Direct and Indirect Materials on Stress Distribution in Class II MOD Restorations: A 3D-Finite Element Analysis Study. BioMed Research International, 2020. 2020(1): p. 7435054.

17. Ferrari Cagidiaco, E., et al., Randomized Clinical Trial on Single Zirconia Crowns with Feather-Edge vs Chamfer Finish Lines: Four-Year Results. International Journal of Periodontics & Restorative Dentistry, 2019. 39(6).

18. Reich, S., A. Petschelt, and U. Lohbauer, The effect of finish line preparation and layer thickness on the failure load and fractography of ZrO2 copings. The Journal of prosthetic dentistry, 2008. 99(5): p. 369-376.

19. Beuer, F., et al., effect of preparation design on the fracture resistance of zirconia crown copings. Dental materials journal, 2008. 27(3): p. 362-367.

20. Åkesson, J., A. Sundh, and G. Sjögren, Fracture resistance of all-ceramic crowns placed on a preparation with a slice-formed finishing line. Journal of oral rehabilitation, 2009. 36(7): p. 516-523.

21. El-Ashkar, A., et al., Evaluation of zirconia crowns restoring endodontically treated posterior teeth with 2 finish line designs and 2 occlusal reduction schemes: A randomized clinical trial. The Journal of Prosthetic Dentistry, 2022.

22. Kasem, A.T., et al., Evaluation of zirconia and zirconia-reinforced glass ceramic systems fabricated for minimal invasive preparations using a novel standardization method. Journal of Esthetic and Restorative Dentistry, 2020. 32(6): p. 560-568.

23. Scutellà, F., et al., A Retrospective Periodontal Assessment of 137 Teeth After Featheredge Preparation and Gingittage. International Journal of Periodontics & Restorative Dentistry, 2017. 37(6).

24. Agustín-Panadero, R., et al., Prospective clinical study of zirconia full-coverage restorations on teeth prepared with biologically oriented preparation technique on gingival health: results after two-year follow-up. Operative Dentistry, 2018. 43(5): p. 482-487.

25. Serra-Pastor, B., et al., Periodontal and prosthetic outcomes on teeth prepared with biologically oriented preparation technique: a 4-year follow-up prospective clinical study. Journal of prosthodontic research, 2019. 63(4): p. 415-420.

26. Di Fiore, A., C. Monaco, and E. Stellini, Retrospective clinical study of 1472-unit monolithic zirconia restorations with feather-edge margins realized with digital workflow. Clinical Oral Investigations, 2023. 27(11): p. 6567-6575.

27. Golshah, A., N. Rezaei, and S. Heshmati, Buccolingual Inclination of Canine and First and Second Molar Teeth and the Curve of Wilson in Different Sagittal Skeletal Patterns of Adults Using Cone-Beam Computed Tomography. International Journal of dentistry, 2020. 2020(1): p. 8893778.

28. León-Martínez, R., et al., Periodontal behavior around teeth prepared with finishing line for restoration with fixed prostheses. a systematic review and meta-analysis. Journal of Clinical Medicine, 2020. 9(1): p. 249.

29. Poggio, C.E., R. Dosoli, and C. Ercoli, A retrospective analysis of 102 zirconia single crowns with knife-edge margins. The Journal of prosthetic dentistry, 2012. 107(5): p. 316-321.

30. Cantner, F., et al., Clinical performance of tooth-or implant-supported veneered zirconia single crowns: 42-month results. Clinical oral investigations, 2019. 23: p. 4301-4309.

31. Golrezaei, M., et al., The Effect of Modified Framework Design on the Fracture Resistance of IPS e. max Press Crown after Thermocycling and Cyclic Loading. The Journal of Contemporary Dental Practice, 2024. 25(1): p. 79-84.

32. Veeraganta, S., The influence of post material, post diameter, and substance loss on the fracture resistance of endodontically treated premolars: A laboratory study. 2022, Dissertation, Kiel, Christian-Albrechts-Universität zu Kiel, 2023.

33. Choi, Y.-S., et al., In vitro evaluation of fracture strength of zirconia restoration veneered with various ceramic materials. The Journal of advanced prosthodontics, 2012. 4(3): p. 162-169.

34. Zidan, S., et al., Assessing tensile bond strength between denture teeth and nano-zirconia impregnated PMMA denture base. International Journal of nanomedicine, 2020: p. 9611-9625.

35. Kim, J.H., et al., Fracture load of zirconia crowns according to the thickness and marginal design of coping. The Journal of prosthetic dentistry, 2012. 108(2): p. 96-101.

36. Torcato, L.B., et al., influence of parafunctional loading and prosthetic connection on stress distribution: a 3D finite element analysis. The Journal of prosthetic dentistry, 2015. 114(5): p. 644-651.

37. Turk, A.G., et al., Effect of different veneering techniques on the fracture strength of metal and zirconia frameworks. The Journal of Advanced Prosthodontics, 2015. 7(6): p. 454-459.

38. Hennig, C.-L., et al., Influence of Root Post Materials and Aging on Fracture Strength and Marginal Gap Quality of Ceramic Crowns—An In Vitro Study. Materials, 2023. 16(11): p. 3985.

39. Larsson, C., et al., Fracture strength of yttria-stabilized tetragonal zirconia polycrystals crowns with different design: an in vitro study. Clinical oral implants research, 2012. 23(7): p. 820-826.

40. Liu, G., et al., effect of cyclic load amplitude on the evolving characteristics of accumulative deformation in subgrade bed. Applied Sciences, 2019. 9(7): p. 1435.

41. Paepoemsin, T., et al., Removal torque evaluation of three different abutment screws for single implant restorations after mechanical cyclic loading. ORAL & implantology, 2016. 9(4): p. 213.

42. Bijelic-Donova, J., et al., Mechanical properties, fracture resistance, and fatigue limits of short fiber reinforced dental composite resin. The Journal of prosthetic dentistry, 2016. 115(1): p. 95-102.

43. Tomić, Z., et al., Phase-field modeling of fused silica cone-crack vickers Indentation. Nanomaterials, 2022. 12(14): p. 2356.

44. Singh, S., et al., Occlusal Contact Surface Changes and Occlusal Force Distribution Between Vacuum-Formed Retainers and Other Retainers: A Systematic Review. Cureus, 2023. 15(12).

45. Barbon, F.J., et al., influence of inorganic filler content of resin luting agents and use of adhesive on the performance of bonded ceramic. The Journal of prosthetic dentistry, 2019. 122(6): p. 566. e1-566. e11.

46. Nakamura, K., et al., effect of cements on fracture resistance of monolithic zirconia crowns. Acta biomaterialia odontologica Scandinavica, 2016. 2(1): p. 12-19.

47. Soares-Rusu, I., et al., Clinical evaluation of lithium disilicate veneers manufactured by CAD/CAM compared with heat-pressed methods: Randomized controlled clinical trial. Operative dentistry, 2021. 46(1): p. 4-14.

48. Preis, V., et al., influence of substructure design, veneer application technique, and firing regime on the in vitro performance of molar zirconia crowns. Dental Materials, 2013. 29(7): p. e113-e121.

49. Johansson, C., et al., Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns. Acta Odontologica Scandinavica, 2014. 72(2): p. 145-153.

50. Ramos, G.F., et al., Failure probability of three designs of zirconia crowns. The International journal of periodontics & restorative dentistry, 2015. 35(6): p. 843.

51. Das, P., et al., Corrosion, stress corrosion cracking and corrosion fatigue behavior of magnesium alloy bioimplants. Corrosion Reviews, 2022. 40(4):p.289 -333.