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Investigation of Fracture Strength and SEM Images of Different CAD-CAM Materials Applied to Two Different Inlay Cavities

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ABSTRACT

Introduction: This study aims to determine and compare the fracture strength and failure modes of zirconia-reinforced lithium silicate glass ceramics (ZLS) and yttria-stabilized zirconia-based ceramic MOD and MO inlay restorations.
Materials and Methods: Stumps representing the maxillary second premolar were prepared using HyperDent software and CAD/CAM milling units. Thirty-two epoxy resin die models were obtained, with 16 samples in each group. Subsequently, restorations were fabricated using Vita Suprinity (VITA Zahnfabrik, Bad Sackingen, Germany) and IPS e.max ZirCAD CAD/CAM (Ivoclar et all., Liechtenstein) blocks to restore the inlay cavities. The specimens were subjected to aging and then tested for fracture using a universal testing machine. The resulting fractures were classified. Data normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated using the Levene test. The interaction between restorative material type and cavity surface was tested using two-way ANOVA.
Results: The fracture strength of IPS e.max ZirCAD material (mean value: 723.18±57.51) is higher than that of Vita Suprinity ZLS material (689.86±113.61), but this difference is not statistically significant (F=3.46, p=0.073). The group with 3-surface cavities in the tooth material (768.00±60.60) has significantly different fracture strength compared to the group with 2-surface cavities (645.037±71.20) (F=47.18, p<0.001).
Conclusions: Having a 3-surface cavity may further enhance the fracture resistance of inlay restorations, and this difference is statistically significant. There is no significant difference in fracture strength among restorative materials.

İki Farklı İnley Kavitesine Uygulanan Farklı CAD-CAM Materyallerinin Kırılma Dayanımı Ve SEM Görüntülerinin İncelenmesi

Makale Bilgisi

Makale Geçmişi

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Sem Analizi.

ÖZET

Amaç: Zirkonya lityum-disilikat cam-seramik ve itriyumla stabilize edilmiş zirkonya bazlı seramik MOD ve MO inlay restorasyonların kırılma mukavemetini ve başarısızlık modlarını belirlemek ve karşılaştırmaktır.
Materyal-Metod: Örneklerin elde edileceği maksillar 2. premolar dişini temsil eden güdükler, CAD/CAM freze ünitesinde hyperdent yazılım kullanılarak hazırlandı. Her bir grup için 16 adet olacak şekilde toplam 32 adet epoksi rezinden die model elde edildi. Daha sonra inley kavitelerini restore etmek için Vita Suprinity (VITA Zahnfabrik, BadSackingen, Germany) ve IPS e.max ZirCAD CAD/CAM (Ivoclar Vivadent Schaan Liechtenstein) bloklardan freze işlemi ile restorasyonlar üretildi. Örnekler yaşlandırma işleminden sonra universal bir test cihazı ile kırılma testine tabi tutuldu. Sonra oluşan kırıklar sınıflandırıldı. Verilerin normal dağılımı Shapiro-wilk testi ile değerlendirildi. Varyansların homojenliği Levene testi ile değerlendirildi. Restoratif materyal türü ve kavite yüzey etkileşimi two way Anova ile test edildi.
Bulgular: IPS e.max ZirCAD materyalin kırılma mukavemeti ortalama değeri (723,18±57,51), Vita Suprinity ZLS mataryelinden (689,86±113,61) yüksektir ancak istatistiksel olarak anlamlı değildir (F=3,46, p= 0,073). 3 yüzeyli kaviteye sahip diş materyal grubu (768,00±60,60), 2 yüzeyli kaviteye sahip olan gruptan (645,037±71,20) önemli derecede farklı kırılma mukavemetine sahiptir (F=4718, p<0,001).
Sonuç: Kavitenin 3 yüzeyli olması, inley restorasyonunun kırılma direncini daha da arttırabilir, ve bu istatistiksel olarak anlamlıdır. Restoratif materyaller arasında kırılma mukavemeti yönünden önemli bir fark yoktur.

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INTRODUCTION

Ceramic materials were first used in dentistry in the late 1700s. The concept of full ceramic restorations was pioneered by Land in 1889.[1] Ceramics exhibit superior properties to other materials, including excellent thermal insulation, biocompatibility, inertness, and exceptional aesthetics.[2] Composite restorations offer reduced polymerization shrinkage, minimal microleakage, and decreased postoperative sensitivity. However, ceramics are prone to fracture due to their structural characteristics in oral conditions.[3] Another disadvantage is that ceramic materials require indirect application, leading to more prolonged clinical procedures than direct restorations.

Dental CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) systems streamline the fabrication of dental restorations. These systems allow for single-session restorations in the dental office. Specifically, CAD/CAM technology produces ceramic blocks that are more homogeneous and have fewer defects or cracks compared to ceramics processed in dental laboratories.[3] Indirect inlays, made from gold, composite resin, or ceramic materials, are commonly used to treat posterior teeth with significant substance loss. Ceramic inlays from these materials are preferred due to their long-term color stability, chemical resistance, fluorescence, high compressive strength, wear resistance, and biocompatibility. However, the leading cause of failure in ceramic inlay/onlay restorations remains margical discrepancies and cohesive fractures.[4]

Materials used in CAD/CAM systems include feldspathic ceramics, leucite-reinforced glass ceramics, lithium disilicate-reinforced glass ceramics, oxide ceramics, glass-infiltrated oxide ceramics, sintered oxide ceramics, nanoceramics, hybrid ceramics, zirconia-reinforced lithium disilicate ceramics, composites, and metals. Restorations made with CAD/CAM have shown clinical success due to technological advancements in CAD/CAM systems.[5] Recently developed, CAD/CAM compatible materials like zirconia-reinforced lithium silicate glass ceramics (ZLS) combine the advantages of zirconia and glass ceramics, offering high mechanical strength, good marginal fit, and excellent aesthetics due to properties such as translucency, opalescence, and fluorescence.[6] The transformation of zirconia from tetragonal to monoclinic phase prevents crack propagation, leading to a 4.5% volume expansion, thus stopping crack advancement.[7] All these features reduce the brittleness and increase the durability of ZLS compared to lithium disilicate ceramics without zirconia.[8]

IPS e.max ZirCAD, produced by Ivoclar, is a Y-TZP block designed for CAD/CAM technology use. The restoration design is processed 20% larger than standard dimensions to accommodate sintering shrinkage.[9]

This in vitro study aims to determine and compare the fracture strength and failure modes of zirconia lithium disilicate glass-ceramic and yttria-stabilized zirconia-based ceramic MOD and MO inlay restorations. The tested hypotheses were as follows: 1) The type of restoration material does not affect the fracture resistance of the tooth-restoration complex, and 2) Different cavity designs do not affect the fracture resistance of the tooth-restoration complex; 3) There is no interaction between the type of restoration material and different cavity designs on fracture strength.

MATERIALS AND METHODS

The necessary ethical approval for this study was received by the Afyonkarahisar Health Sciences University Non-Pharmaceutical and Medical Device Ethics Committee (approval date: 07.04.2023, protocol number: 2023/4). To ensure standardization, stumps representing maxillary second premolar teeth were prepared using CAD/CAM milling units with Hyperdent software.

Restorative Procedures

The die dimensions were mesiodistal width of 6 mm, buccolingual width of 8 mm, and crown length of 7.5 mm. The inlay cavity was prepared with a depth of 1.5 mm from the deepest point (fissure, the anatomical area between tooth cusps) to the cavity floor (the largest horizontal area between the shoulders). The proximal surface dimensions in the buccolingual direction were 4 mm. The shortest isthmus distance in the buccolingual direction on the occlusal surface was 4 mm. The shoulder width was 1.5 mm, and the shoulder depth was 1.5 mm from the cavity floor. The cavity surface angle from the cavity floor to the occlusal surface was 6°. The samples were divided into mesio-occlusal (MO) and mesio-occlusal-distal (MOD) cavities. 32 epoxy resin die models (16 for each group) were prepared. Subsequently, restorations were milled from Vita Suprinity and IPS e.max ZirCAD CAD/CAM blocks to restore the inlay cavities. The fabricated restorations were cemented onto epoxy resin dies using resin cement. Four different groups were obtained (n=32), as shown in Figure 1.

1.IPS e.max ZirCAD (E group)

- 1a.MO (mesio-okluzal) IPS e.max ZirCAD (emo)
- 1b.MOD (mesio-okluzal-distal) IPS e.max ZirCAD (e mod)

2.Vita Suprinity ZLS (V group)

- 2a.MO (mesio-okluzal) Vita Suprinity ZLS (vmo)
- 2b.MOD (mesio-okluzal-distal) Vita Suprinity ZLS (vmod)

Figure 1: Study design

The inner surface of ceramic inlays was treated with hydrofluoric acid for 20 seconds using a brush. Next, they were rinsed with water for 60 seconds and dried with air for 20 seconds. Silane agent was then applied to the hydrofluoric acid-treated ceramic inlay surfaces using a brush, creating a thin layer, and air-dried for 3-5 seconds. Materials are shown in table 1. After each inlay's surface treatment, they were cemented with RubySE CEM (Inci Dental, Türkiye) using resin cement on an epoxy resin die. The inlays' buccal, lingual, distal, and mesial surfaces were polymerized by exposing them to 20 seconds of light from an LED device, and the cementation process was completed for 32 samples (Figure 2). The samples were then embedded in acrylic resin (Figure 3).

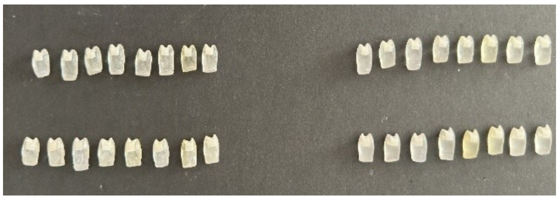


Figure 2: Samples with cementation completed

Figure 3: Sample embedded in acrylic resin

Fracture load test

The specimens were soaked in distilled water at 37°C for 24 hours to simulate temperature changes that could occur in the oral environment. The samples were then subjected to a thermal cycling process between 5°C and 55°C, with 10-second intervals and 20 seconds of exposure at 5000 cycles (MTE-101; Moddental, Ankara, Türkiye).

Tablo 1: Materials used in this study

Name	Type	Manufacturer
IPS e.max ZirCAD	4 mol% yttrium stabilized zirconia (4Y-PSZ)	Ivoclar Vivadent (Schaan, Liechtenstein)
Vita Suprinity	zirkonya lityum-disilikat	VITA Zahnfabrik, BadSackingen, Germany
Porcelain Etch & Silane		Ultradent
RubySE CEM		İncidental/ İstanbul,

		Türkiye

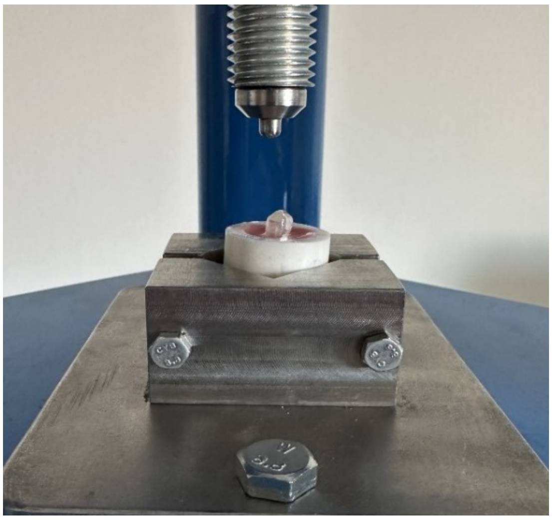


Figure 4: An image before the fracture

Before the fracture test, the specimens were fixed in self-polymerizing acrylic resin. A 5 mm diameter stainless steel ball located on the upper part of the universal testing machine was placed perpendicular to the crowns occlusal surface (Figure 4). The crowns occlusal surfaces were loaded with a 1 mm/min loading rate until fracture occurred (Moddental, Ankara, Türkiye). The force values at fracture were recorded in Newtons (N).

Fracture mode and microstructure analysis

In the study, the specimens subjected to the fracture resistance test were examined under a microscope (Zumax Oms1950 Basic, Zumax Medical, China) at 19x magnification to determine the fracture types after completing the test (Figure 5). The evaluation of fracture types was based on Burke's classification.[10] According to this classification, the fracture types were recorded according to the following criteria:

Tip I: Minimal breaks or cracks in the crown,

Tip II: Fracture of less than half of the crown,

Type III: Crown fracture along the midline or fracture or displacement to the end of the crown,

Tip IV: Fracture of more than half of the crown,

Tip V: It indicates that catastrophic fractures are seen when the crown breaks.

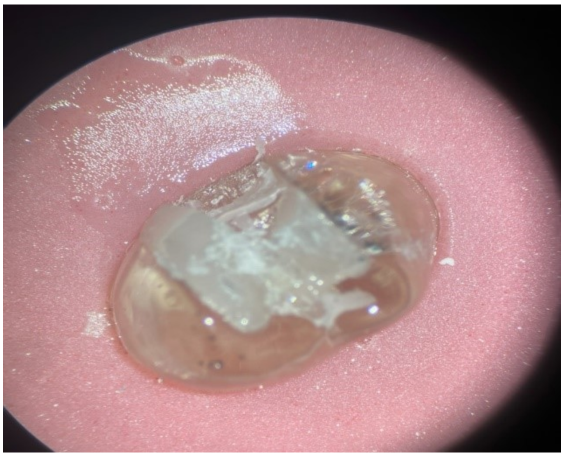


Figure 5: Examination of broken samples under a microscope

After the fracture process, SEM (LEO 1430 VP) analysis was performed on a specific sample from each group for detailed examination. Before SEM examination, the surfaces of the fractured samples were coated with a thin layer using a carbon sputter coater (BAL-TEC SCD 005 Sputter Coater). The fractured surfaces were evaluated at magnifications of x50, x100, x150, and x250 (Figure 6).

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). The normal distribution of the data was assessed using the Shapiro-Wilk test. The homogeneity of variances was evaluated using the Levene test. The interaction between the type of restorative material and cavity surface was tested using a two-way ANOVA. P-values less than 0.05 were considered statistically significant.

RESULTS

The groups' data exhibited a normal distribution according to the Shapiro-Wilk test ($p>0.05$). Variance homogeneity was confirmed using the Levene test ($p=0.299$). The analysis results related to fracture resistance of the test groups are presented in Tables 2 and 3.

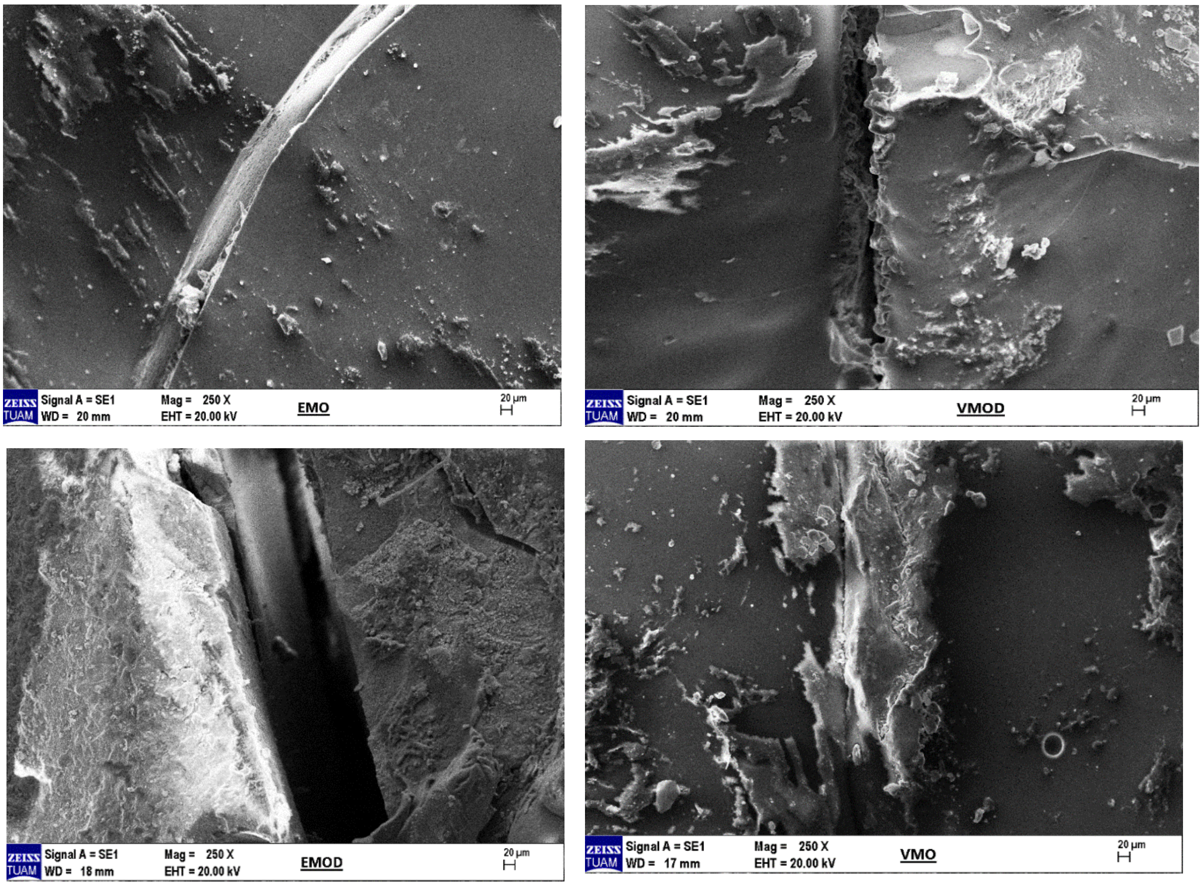


Figure 6: SEM image after fracture of 1 sample from VMO, VMOD, EMO, EMOD groups (Fracture line-epoxy model and resin cement images)

Table 2: Two-way analysis of variance

Source	Sum of squares	df	Mean square	F	P value
Intercept	15973541.12	1	15973541.12	6229.60	*<0.001*
Material group	8881.11	1	8881.11	3.46	0.073
Cavity group	120970.51	1	120970.51	47.18	*<0.001*
Material *Cavity	50474.59	1	50474.59	19.68	*<0.001*

Table 3: Means and standart deviations of groups

	Two surface		Three surface		Total		P value
	n	Mean±std	n	Mean±std	n	Mean±std	
IPS emax ZİRCAD	8	701.41±51.35	8	744.95±58.05	16	723.18±57.52	0.073
VİTA SUPRİNİTY ZLS	8	588.66±31.06	8	791.06±57.32	16	689.86±113.61	
Total	16	645.04±71.21	16	768.01±60.60			*<0.001*

One-way analysis of variance

According to the analysis, the average fracture strength of the material in Group 1 (IPS e.max ZirCAD) (723.18±57.51) is higher than that of Group 2 (Vita Suprinity ZLS) (689.86±113.61). However, this difference is not statistically significant (F=3.46, p=0.073).

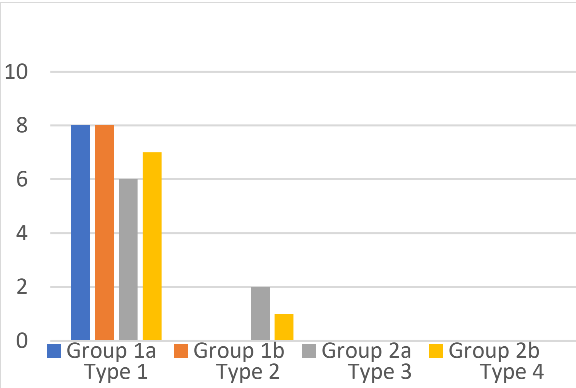
The dental material group with three-surface cavities (768.00±60.60) significantly differs in fracture strength from the group with two-surface cavities (645.037±71.20) (F =47.18, p<0.001).

The two-way ANOVA results indicate that the interaction between restorative material type and cavity significantly affects fracture strength (F=19.68, p<0.001) (Table 2).

The highest average fracture resistance is observed in Group 2b (Vita Suprinity ZLS-MOD) (791.06±57.31), while the lowest fracture resistance is found in Group 2a (Vita Suprinity ZLS-MO) (588.66±31.05) (Table 3).

All samples exhibited repairable fractures in Group 1a (emo) and Group 1b (emod). However, in Group 2a (vmo), two samples showed irreparable fractures, whereas in Group 2b (vmod), one sample had an irreparable fracture (Table 4).

Tablo 4: Fracture type



DISCUSSION

Using tooth-colored inlays as a restorative method offers several advantages, including high aesthetic value, good marginal fit, reduced tooth structure loss, and the preservation of more healthy dental tissue. Furthermore, advancements in CAD/CAM systems have made the clinical placement process of inlays more efficient and practical, significantly enhancing restoration quality and reducing patient visit duration. Therefore, this study aims to determine and compare the fracture strength and failure modes of lithium disilicate glass-ceramic and yttrium-stabilized zirconia-based ceramic MOD and MO inlay restorations.

Clinical research often requires five years or more. Due to high costs, researchers are often limited to a small sample population, and results may be incomplete due to variability within the patient population. When natural teeth are used, achieving standardization is challenging due to differences in size, mineralization percentage, anatomical configuration, variations in pulp size across different age stages, and internal cracks in each tooth. Additionally, several parameters, such as the storage process of extracted teeth and the conditions under which selected teeth are extracted, can influence study outcomes when natural teeth are employed.[11] To obtain results closer to clinical conditions while investigating the fracture resistance of ceramics, the die material's elastic modulus needs to resemble that of natural teeth. Scherrer and de Rijk [12] reported that as the die material's elastic modulus increases, all-ceramic restorations' fracture strength also increases. Therefore, this study was conducted in vitro using models made from epoxy resin, which closely approximates the elastic modulus of natural teeth.

The existing literature has no consensus on the required fracture resistance for premolars with MO and MOD inlay restorations to ensure long-term success. Dental restorations routinely experience masticatory forces. The average forces applied during chewing range from 11 N to 150 N. In the anterior region, this value can reach up to 200 N, while in the posterior region, it can go up to 350 N. In cases of parafunctional habits, forces of up to 1000 N have been reported. Therefore, restorations in the posterior region must withstand these forces.[13] Our study found that the fracture resistance values of the tested restorations exceeded physiological masticatory forces. According to our results, the highest fracture strength was observed in Group 2b.

Keshvad and colleagues [14] compared the fracture resistance of 15 premolars restored with inlays made from leucite-reinforced ceramic IPS Empress CAD (Ivoclar et all.). They measured the maximum load at the moment of fracture as 1050±763 N.

Liu et all.[15] conducted an experiment using yttrium-stabilized zirconia-based ceramic to restore 16 molar teeth (divided into two groups: one with proximal boxes and one without). They reported a maximum load of 1799.78±338.88 N, with the group having proximal boxes reporting 2004.89±183.59 N (n=8) at the point of fracture.

In a study conducted by Şener-Yamaner et all.,[16] they compared the average fracture resistance of 20 premolars restored with lithium disilicate ceramic inlays (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). The lithium disilicate ceramic inlays group exhibited an average fracture resistance of 2007±29.5 N, while the intact teeth group showed 2594±35.52 N.

Soares et all.[17] reported that when subjected to a static load of 1675 N, the samples had an average survival rate of 93%.

Yoon et all.[18] tested small premolars with lithium disilicate ceramic inlays. After aging the specimens, they obtained an average load of 661.85±302.95 N using a universal testing machine, consistent with the results from Yoon et all.'s study. This study's findings differ from those of other studies, and we attribute this discrepancy to the use of small premolars.[14-17]

Al-Akhali et all.[19] found that polymer-based occlusal veneers significantly reduced the ultimate fracture strength due to thermomechanical fatigue. However, this reduction was not observed in lithium disilicate glass ceramics. According to Barakat et all.[20], Vita Suprinity restorations exhibited statistically insignificant but higher average fracture resistance than E-max restorations. These observations highlight the significant role of zirconia particles in the crystallization process and the effects of added zirconia on fracture durability.[21] Similarly, this study showed no statistically significant difference in fracture resistance between the “ZLS VITA Suprinity PC” material and the "IPS e.max ZirCAD” material.

A 3D finite element analysis study demonstrated that the only cavity design is more effective in preserving tooth structure than the inlay design for adhesive-bonded lithium disilicate ceramic restorations.[22] Inlays with inappropriate distribution and high-stress levels may render these restorations more prone to fracture and leakage.[23] In this study, three-surface cavities exhibited significantly higher fracture resistance than two-surface cavities. This could be because three-surface cavities allow for a more balanced distribution of forces. Consequently, stress on the restoration is more homogeneously distributed, leading to increased fracture resistance. In a study, they evaluated the stress distribution on models prepared in the remaining tooth tissue and observed that preserving the remaining tooth tissue increased the stress on the restoration while decreasing it on the tooth tissues.[24]

On the other hand, MOD caries are caries in which there is more tooth tissue loss than MO caries. The more tooth tissue loss, the more permanent the possibility of a tooth fracture. It should also be kept in mind that fractures in the tooth are more important than fractures in the restorative material.

In addition to fracture resistance, analyzing failure modes in samples was crucial for predicting restored teeth' clinical performance and prognosis. Some studies have indicated that restorations created without damaging the underlying tooth structure and cohesive fractures involving the cement layer are common.[25,26] Our study’s results align with these observations.

However, this study has certain limitations. Firstly, the continuous vertical load must represent clinical applications more precisely. Furthermore, real-life masticatory cycles involve complex forces that subject ceramics to different axes (vertical and lateral). Cyclic loading may more accurately simulate fatigue failures observed in clinical practice. Clinical loading varies due to repeated exposure to minor forces, which can impact tooth restorations and lead to failure. One of the significant limitations of our study is that the specimens used were represented by alternative materials instead of natural teeth this limitation should be considered.

CONCLUSION

1. A three-surface cavity design may further enhance the fracture resistance of inlay restorations, and this finding is statistically significant.
2. There is no significant difference in fracture strength among restorative materials.
3. Nearly all restorations achieved repairable failures.

Ethical Approval

The necessary ethical approval for this study was received by the Afyonkarahisar Health Sciences University Non-Pharmaceutical and Medical Device Ethics Committee (Decision no: 2023/4).

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Conflict of Interest

The authors deny any conflicts of interest related to this study.

Author Contributions

Design: RZE, KK, Data collection or data entry: RZM, KK, Analysis and interpretation: RZM, Literature review: RZM, KK, Writing: RZM.

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