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Research Article

Failure Load Resistance of Different Repaired CAD/ CAM Ceramic Crowns Following Endodontic Access Preparation

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Abstract

Aims: This study aimed to evaluate the fracture resistance of different CAD/CAM ceramic crowns following standardized endodontic access preparation and repair using two restorative protocols.

Materials and Methods: Ninety extracted human maxillary premolars were prepared for full-coverage crowns and restored with lithium disilicate (LD), yttria-stabilized tetragonal zirconia polycrystal (ZR), or polymer-infiltrated ceramic (VE) (n=30 per group). Each group was subdivided into three subgroups (n=10): intact crowns, crowns with access preparation repaired using a porcelain repair kit (GC), and crowns repaired with composite resin (Filtek Z350 XT). Endodontic access cavities were standardized using a custom template and prepared with diamond burs under water cooling. Specimens underwent thermomechanical loading, followed by fracture testing in a universal testing machine. Data were analyzed using one-way ANOVA and Duncan multiple range tests (α=0.05).

Results: ZR crowns exhibited the highest fracture resistance across all conditions (mean intact: 3887.3 N; GC repair: 3371.7 N; composite repair: 2955.3 N), followed by LD (2742 N; 2281.5 N; 1960.2 N) and VE (1849.4 N; 1397.8 N; 1281.2 N). Access preparation significantly reduced fracture resistance in all materials ($p<0.05$). Repair using GC yielded significantly higher fracture resistance than composite in ZR and LD, but not in VE. Most failures (60%) were unfavorable, with oblique cusp fractures predominating.

Conclusion: Endodontic access preparation significantly weakens CAD/CAM crowns regardless of material or repair method, although all tested crowns (ZR, LD, and VE) maintained fracture resistance above maximum reported masticatory forces (500–700 N). Zirconia crowns demonstrated superior mechanical performance, and GC-based repair provided better strength recovery in ZR and LD.

Keywords: CAD/CAM crowns, Endodontic access, Fracture resistance, Lithium disilicate, Polymer-infiltrated ceramic, Repair material, Zirconia.

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INTRODUCTION

Whenever a viable tooth is planned to be prepared for complete coverage restoration, it has to be tested for pulp vitality since complications are prone to appear upon carrying on the endodontic process with the presence of the definitive restoration (reports show an incidence of 15% of such complications) (1).

Endodontic treatment for such patients is known to be extremely challenging for two main reasons. First, clinical landmarks required to orient and locate the pulp chamber are few, and hence clinical judgment is used to proceed through the access opening design. Second, a tremendous amount of dentin foundation has to be cut on access preparation, which causes this foundation to be significantly weaker and difficult to assess whether it is sufficient to support the future crown. Furthermore, ceramic crowns are poor conductors of heat, which makes heat generation control during access opening preparation quite hard to control, and residual stresses will be generated (2).

Respond to the access openings that differ among ceramic systems. All ceramic crowns are the most susceptible to edge chipping around the hole of the access opening, which is more likely to happen and causes the restoration to be more subject to crack formation and propagation (3).

Currently, no universally accepted clinical protocol is standardized for managing a complete coverage crown upon access opening. The decision whether to repair or replace the crown depends on clinical judgment. Decision-making is influenced by external considerations in addition to the amount of damage incurred during the access. If the decision is to keep the restoration, for example, anterior restoration to preserve the esthetics, the access preparation effect on the longevity and fracture resistance of such restorations is crucial (4).

The bond strength between the crowns and the repairing materials also has a great impact on the fracture toughness of the crown. Any defect in the adhesive interface between the two substrates can change the failure mode of the crown and cause the results to be inapplicable (5).

The decision to save a crown is a financial issue for the patients and preferable for the dentist, especially if the crown is new. The ideal treatment plan is to remove the crown before endodontic treatment and re-cement after treatment completion.

Unfortunately, crown removal is quite difficult, and the crown is subjected to damage during the removal process. Also, the tooth itself could be damaged. Moreover, mostly the crowns are cemented by resin cements, which negatively affects the removal of the crowns, making the option to perform access preparation through the crowns more advisable (6).

Evidence on the access opening preparation effect upon the fracture resistance of crowning materials is very little. This present study aims to test the influence of access opening preparation on the fracture resistance of lithium disilicate, yttrium-stabilized tetragonal zirconia, and polymer-infiltrated ceramic with varying repairing materials.

The null hypothesis of this study states that neither the type of crown material nor the type of repairing materials used affected the fracture resistance of the tested samples.

MATERIALS AND METHODS

Ethical Approval

The ethical approval for this study was obtained from the committee of ethics in the College of Dentistry, Mosul University (**H.DM.44/22**).

Ninety maxillary premolars extracted were used as abutments (aged between 18-20 years), and all the patients were informed and consented to the study. The examined samples were stored in a 0.5% chloramine-T solution for 30 days in order to achieve adequate disinfection and to avoid dehydration with no side effects on the dentin (7).

A stereomicroscope (30x) (Leica M80, Leica Microsystems, Wetzlar, Germany) was used to examine each tooth to check for any cracks, carious lesions, or other defects. The dimensional range of the examined premolars was (width mesiodistally: 6±0.5 mm; width buccolingually: 8±0.5 mm, and crown length: 7.5±0.5 mm). Size of the pulp chamber (height of the pulp horn: 3.8±0.5 mm buccally; lingually: 3.1±0.5 mm; width: 2.9±0.5 mm).

Brass tubes (15 mm diameter) were used to fix the teeth. The root surface was covered 2 mm apically to the cemento-enamel junction using a 0.2-mm-thick periodontal membrane(artificial) made of gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar, Hilden, Germany). Then, the coated roots were fixed in the brass tube using auto polymerized resin.

Teeth preparation was done using a handpiece fixed to a paralleling machine (custom-made) with a 120-degree angulated adaptor to standardize the path of insertion. Cutting was established to obtain a finishing line of 1–1.2 mm (butt joint finishing line), and occlusal reduction was standardized to be 1.5–2.0 mm. While the angle of axial convergence was standardized to 10° (tolerance ±2°). Copious water coolant was used during the preparations with controlled pressure (approximately 2 N). Digital caliper (0.01 mm) associated with stereomicroscopy (×10–20) was used to verify the dimensions (Figure 1) (8).

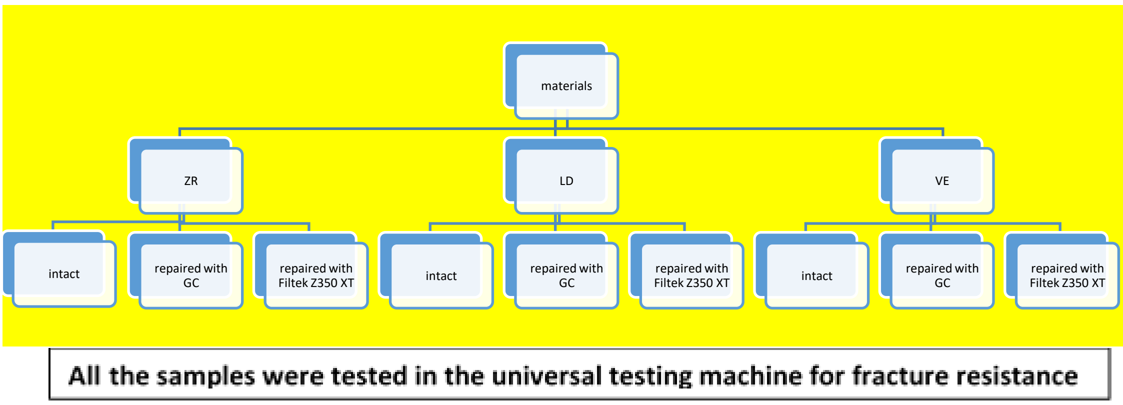

Figure (1): Experimental flaw chart for the tested materials.

Teeth Grouping

The samples were divided randomly into 3 groups depending on the type of restorative material used (lithium disilicate IPS e.max CAD, zirconia Mixed Cubic–Tetragonal (cubeX2), and polymer-infiltrated ceramic VITA Enamic)(Figure 2). The restoration was cemented using self-adhesive resin cement (RelyX Unicem2, 3M ESPE, USA) using constant pressure, which was assured by using the universal testing machine with a 5 kg weight (≈ 49 N) for 10 min applied on the occlusal applicator (Teflon or stainless tip) applied along with the long axis of the tooth. After the excess cement was removed, light curing was done using an LED visible-light curing unit (Bluephase G2, Ivoclar Vivadent) for 40 seconds on each surface (9).

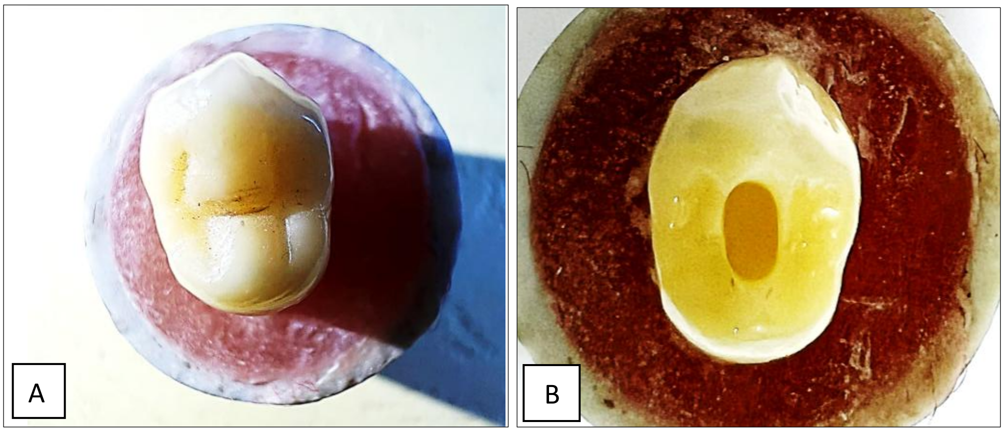

Figure (2): Examined teeth, a) before preparation, b) after preparation

The specimens in each group were further subdivided into 3 subgroups of ten specimens each. Group I represents the control and remained intact, while Groups II and III underwent standardized endodontic access cavity preparation.

To ensure uniformity, the access outline was first marked on a reference specimen. After completing the preparation on this reference, a template (plastic) was used to mark identical access outlines on all the examined crowns. Preparations were standardized with a 2 mm occlusal reduction, a wide 2 mm butt-joint finish line located 1 mm above the cementoenamel junction, and a minimum 3 mm pulp chamber depth. Internal walls were prepared with 6–10° divergence and rounded internal line angles.

The preparations were done by the same experienced clinician using a handpiece operating at 200,000 rpm under copious water irrigation, applying consistent pressure. A tapered diamond bur (round-end) with coarse-grit (ZR6856.016; Komet), known for its efficiency in cutting ceramics, was used, with a new bur for each specimen.

In the current study, root canals were not performed after doing access preparation as the test in mainly focused on the effect of the access preparations and the endodontic treatment may vary between the teeth (different size and parameter of endodontic instruments used) with the irrigation solutions (sodium hypochlorite, chlorehexidine and EDTA) also affecting the dentin surface which has negative effect on the bonding strength of the endocrown. Furthermore, the sealing materials (ZOE or bioceramics) has variable effect on the bonding. Recent studies also omitted the use of endodontic treatment for the aforementioned reasons (10,11).

In Group II, the access openings were repaired using a special kit of porcelain repair system (GC Repair Kit; GC, Tokyo, Japan) and restored using a direct resin composite (G-aenial Posterior, GC, Tokyo, Japan). The repair protocol involved applying Ceramic Primer II to the ceramic surfaces, followed by G-Premio Bond to all bonding areas, including any exposed tooth structure, and light curing for 10 seconds with an LED curing unit (Elipar Highlight; 3M ESPE, Seefeld, Germany). The access cavity was then filled with resin composite (RelyX Ultimate (3M ESPE, USA) in two 2-mm increments. Each increment was light-cured for 40 seconds. The occlusal surface was leveled with surrounding margins and finished and polished using an aluminum oxide disc system (coarse to superfine) (Sof-Lex XT; 3M ESPE, USA).

In Group III, the dentin surface was refreshed with a bur, etched using 37% phosphoric acid for 30 seconds, washed, and gently dried. Universal Adhesive bond RelyX Ultimate (3M ESPE, USA) was then applied and light-cured for 10 seconds. Then the cavity was incrementally restored with Filtek™ Z350 XT Universal Composite (3M ESPE, USA, each cured for 40 seconds. Finishing and polishing were performed as done for Group II.

All the samples were stored at static conditions of 37 °C and 100% humidity for 24 hours before being subjected to thermo-mechanical loading (TML).

Mechanical cyclic loading was performed using a chewing simulator, where a stainless-steel stylus contacted the functional cusp. A constant load of 50 N was applied for 100,000 cycles at a frequency of 1.6 Hz. Following TML, each crown was examined for surface damage, microfractures, marginal integrity, and any signs of debonding. Fracture resistance testing was then performed using a universal testing machine (Lloyd Instruments; UK) with a cross-head speed of 0.5 mm per minute. The load was applied with a 5 mm round-ended stainless-steel piston positioned in the central fissure to simulate occlusal contact, targeting the crown–composite repair interface in repaired specimens (Figure 3). Fracture resistance was measured using the following equation:

Fracture resistance (N) = P_{max}

where P_{max} is the peak load recorded when the specimen fails (unit: N).

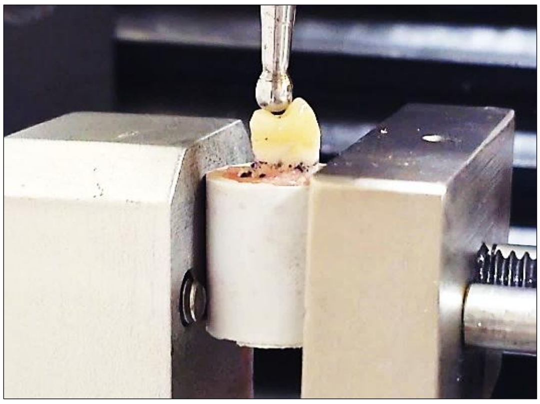

Figure (3): The samples positioned in the universal testing machine.

RESULTS

The descriptive statistics of the tested materials showed the mean, minimum, and maximum values of fracture resistance (Newton) as represented in Table (1).

Table (1): shows the descriptive statistics with means and standard deviations of the tested materials.

Materials		Mean ±SD	Minimum	Maximum
ZR	Intact [a]	3887.3 ± 289.19	3567	4320
	Rep. GC [b]	3371.7 ± 307.52	2934	3853
	Rep.comp [c]	2955.30±235.08	2678	3350
LD	Intact [d]	2742±158.86	2556	3045
	Rep. GC [e]	2281.5±253.99	1845	2598
	Rep.comp [f]	1960.2±189.40	1689	2349
VE	Intact [g]	1849.4 ±171.07	1567	2145
	Rep. GC [h]	1397.8±197.07	1134	1753
	Rep.comp [h]	1281.20±213.47	1045	1786

Different letters represent a significant difference, while the same letters represent no significant difference.

VE group, which showed no significant difference between the two repairing materials ($p>0.05$), while ZR and LD showed a significant difference between the repairing materials ($p <0.05$), as shown in Table (2).

Table (2): One-way ANOVA test of all the examined groups.

		Sum of Square	Df	Mean Square	F	Sig.
INTACT	Between Groups	9177900.613	2	4588950.307	148.077	.000
	Within Groups	278913.334	9	30990.370		
	Total	9456813.947	11			
COMPOSITE REPAIR	Between Groups	7880455.074	2	3940227.537	330.058	.000
	Within Groups	107442.001	9	11938.000		
	Total	7987897.075	11			
GC REPAIR	Between Groups	8109344.015	2	4054672.008	149.626	.000
	Within Groups	243888.667	9	27098.741		
	Total	8353232.682	11			

The data of the fracture test for all nine groups were normally distributed. One-way ANOVA and Duncan multiple comparison were applied and showed that significant differences were found in fracture resistance among the examined materials, as shown in (Figure 4).

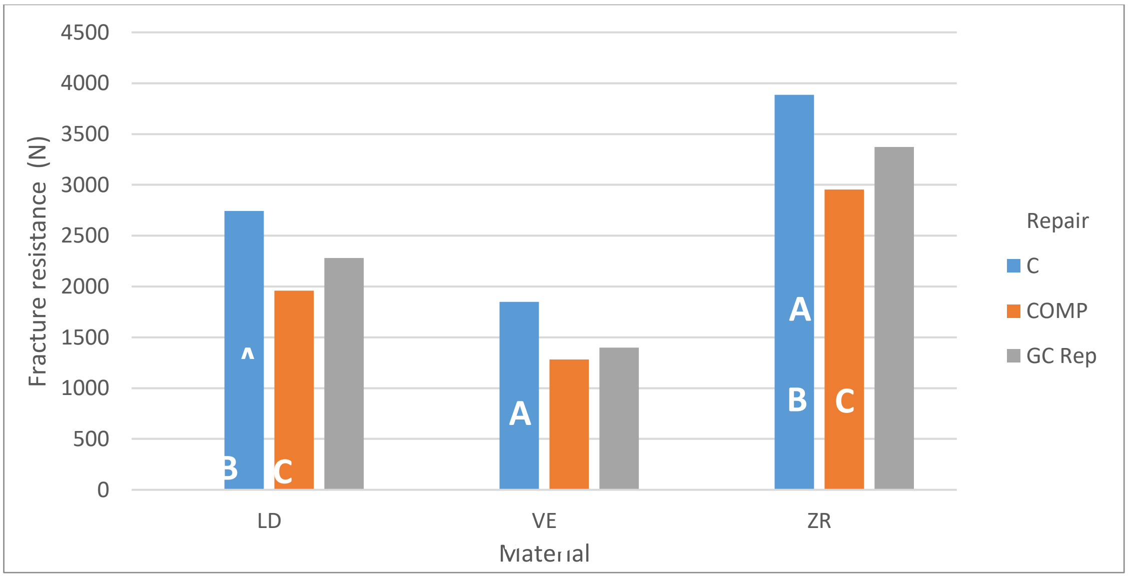

Figure (4): Duncan multiple variant analysis of all the tested groups. Whereas similar letters represent no significant difference, while different letters represent a significant difference.

To determine the level of significance, Duncan's multiple variant tests was done and showed that there was a significant difference within each group. Regarding the intact, repaired with composite, and repaired with GC groups of different tested materials, as shown in Figures (5-7).

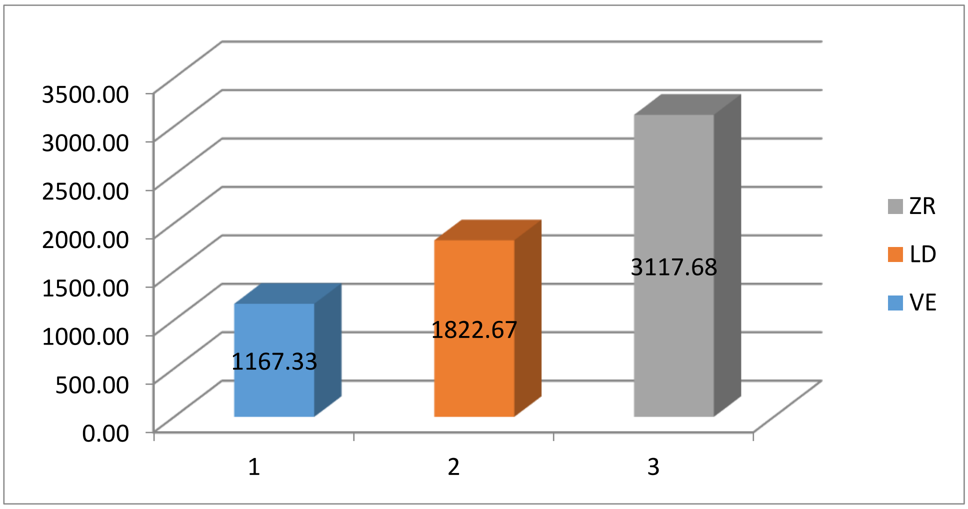

Figure (5): Duncan multiple variant analysis of the **INTACT** tested groups.

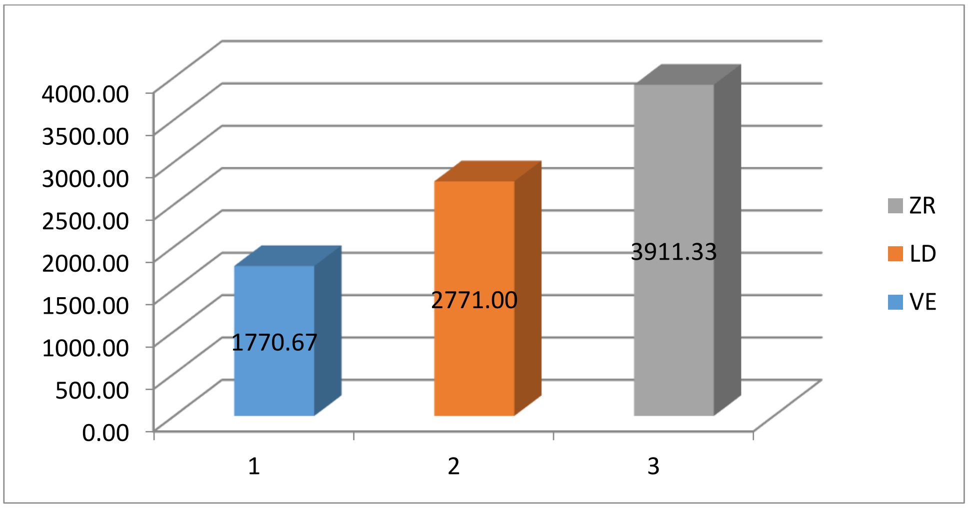

Figure (6): Showing the Duncan multiple variant analysis of the **Repair with composite** tested groups.

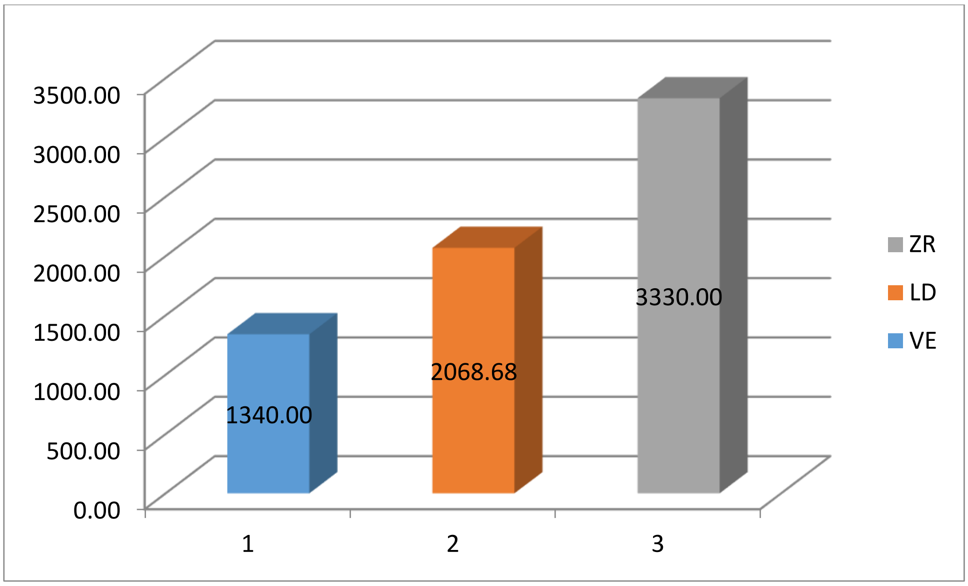

Figure (7): Duncan multiple variant analysis of the **Repair with GC** tested groups.

Table (3) shows the failure modes. Unfavorable fractures are the most common failure modes in all the groups in a percentage of (60%). The oblique shearing within the buccal cusp, which extended to the coronal third of the root, represents the majority of the failure modes (50%). Loss of adhesion and complete fracture were shown in only one sample; a fracture in the mesiodistal direction was observed in one sample (Figure 8).

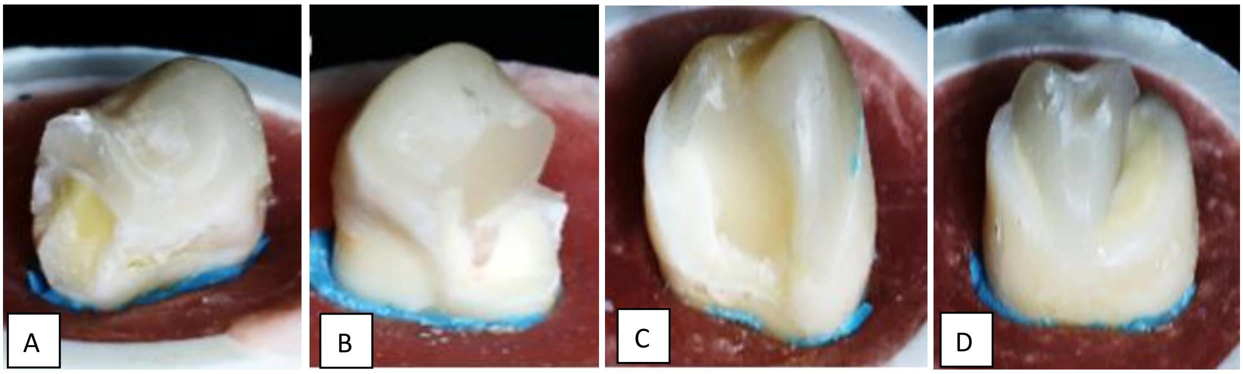

Figure (8): Modes of failures, a) favorable buccal cusp fracture, b) unfavorable buccal cusp fracture, c) unfavorable palatal cusp fracture, d) unfavorable both cusps fracture.

Table (3): Frequencies of different fracture modes

Unfavorable fracture	ZR	LD	VE
Buccal cusp	4	4	3
Palatal cusp	2	2	3
Both cusps		1	
Favorable fracture			
Buccal cusp	1	1	2
Palatal cusp	2	2	1
Both cusps	1		1

DISCUSSION

Full-coverage restorations are usually used in teeth with extensive loss of structure which could happen due to trauma or caries. Crown preparation is not considered as a conservative procedure, and in certain situations, about 24% to 70% of the tooth structure has to be removed (12). During such preparation, heat generation and mechanical trauma are likely to affect the pulp, from which the pulp may not recover completely, and lead to permanent damage to the tissue (e.g., stressed pulp condition) (13).

Performing access preparation within ceramic crowns is usually done using high-speed diamond burs, which subject the ceramic to loading strain, leading to cracks, causing structural weakness (12). Complete crown failures are more likely to occur while performing endodontic access opening on all full ceramic crowns, while Grobecker-Karl reported that zirconia crowns are less prone to fracture during endodontic access (14).

Fracture resistance is considered one of the most essential features of dental ceramics. It represents the resistance of the material to crack propagation resulting from internal defects. Such cracks can lead to microscopic fractures within the margins of the restoration or be less likely to bulk fracture (15).

In order to achieve more reliable results, human extracted premolars were used, so the chances of results misinterpretation will be decreased. The teeth used were selected with nearly the same size of pulp chamber, which was confirmed by using radiographic examination and digital calipers (16).

The access cavities were performed in the same outline using a template, with a depth of penetration of 4 mm 6 which was considered adequate as it provides adequate perforation into the crowning material, which was assured using marked cylindrical diamond burs. (17)

The load was vertically applied until the occlusal surface of the crowns fractured. The direction of the applied force was used because it simulates the occlusal relationship of the examined teeth, in which the loading pattern is vertical and applied parallel to the long axis of the tooth (18,19).

The most important factors that affect the fracture resistance of the restorative materials are elastic modulus and fracture toughness. The modulus of elasticity of the crowning materials affects the capability of the restored teeth to resist fracture (20). As VITA Enamic has a modulus of elasticity similar to that of natural dentin, the force at the luting interface is spread out more evenly. This wider stress distribution helps both the crown and the tooth resist fracture more effectively (21). These results agreed with other studies, in which Vitaenamic (polymer-infiltrated ceramic) tends to be more flexible and tougher than glass-matrix ceramics (lithium disilicate), resulting in more favorable patterns of fracture in this material (22). Whereas rigid materials (zirconia) with high elastic modulus will not be able to absorb and redistribute the force effectively to the residual tissue, leading to increased stress within the tooth (23,24). In addition, the greatest stress in zirconia tends to occur on the side opposite where the load is applied, leading to higher tensile stress near the cement–restoration margin. This makes the tooth more prone to root fractures and potential failure, as shown in Table (3) (25).

As for the fracture resistance, which is considered the most valuable property of ceramics to resist crack propagation (26), Zirconia material is made of crystals with no glassy phase, while Vita Enamic and IPS E-max are mainly composed of crystal-reinforced glassy phase. Cracks are more likely to start and spread within the glassy phase and along the glass–crystal interfaces once the applied forces exceed a critical threshold. For this reason, the ZR group better resisted the higher loads than other materials (15,27).

Vita Enamic material has a dual-network structure, whereas the dominancy of its structure is a ceramic network reinforced by a network of polymers, and this composition combines the positive characteristics of both ceramic and composite. The polymer network provides a remarkable absorption of the intraoral forces, and for this reason, this material is considered a promising choice to be used for posterior crown restorations. Also, it has better bonding characteristics with an elasticity close to that of the dentin (28,29).

Regarding the effect of the repairing materials, the result showed that the fracture resistance was decreased significantly for all the tested materials due to the weakening resulting from the access opening and the pressure and vibration associated with preparation, producing microcracks in the structure of the crowning materials, as shown in (Figures2-4) (12). These results were in agreement with Shaker et al. (30), who stated that access cavities cause a significant loss of strength of all ceramic crowns.

Recent studies, such as Zimmermann et al. (14), showed that there was no difference in the fracture strength of LD crowns before and after preparation for endodontic access, which disagreed with the results. The authors suggested that lithium disilicate crowns are strong enough to handle the stresses from endodontic access preparation, so their overall structural integrity remains largely unaffected (31).

Also there was significant difference between the repairing materials for zirconia and lithium disilicate crowns except for the vitanemic which showed no significant difference among both the repairing materials and this result is explained by the close similarity in the structural composition of the vitanemic and the repairing materials because all of them are composed of polymer and this leads to more intimate integration among the materials and better distribution of the force as shown in (Figure1) (32).

Some authors stated that the acid etching with Lithium disilicate ceramics improves the micromechanical interlocking along with the tooth surface. Therefore, LD is preferred to be used for the construction of conventional crowns and endocrowns over other materials due to the adhesive capability of this material (33).

Monobond Etch & Prime significantly enhances bond strength, even when used as a single-step treatment. Because of this, samples repaired with the GC repair kit showed higher fracture resistance compared to those repaired with other materials (34).

The main goal of the study was to evaluate the impact of endodontic access on the fracture resistance of zirconia, lithium disilicate, and Vitaenamic crowns. Regarding the results obtained in our study, the first null-hypothesis claimed that restorative material type does not affect the fracture resistance was rejected. Also, the second null-hypothesis, which suggested that the repairing material would not affect the fracture resistance, was partially rejected for the tested materials.

Significant differences were found in the fracture resistance of the examined samples in the varying groups. The zirconia group scored the highest mean fracture load (4320 N), as Zirconia has superior mechanical properties related to the polycrystalline structure, compared to Vitaenamic and IPS E.max CAD (10).

A limitation of this study is the natural variation in tooth size. While all the teeth were carefully selected to fall within a similar size range, and their pulp chamber dimensions were measured using CBCT for accuracy, a small difference of about ±0.5 mm remained. Even such a minor variation could have influenced the fracture resistance results. Furthermore, in vitro testing conditions, which cannot fully replicate the forces and fatigue seen in the mouth, may also have affected the results. Minor variations in crown preparation, thickness, and cementation technique could further explain differences compared with other studies.

This study has clinical significance as the clinicians will be more enlightened when selecting the type of restorative material and preparation design with the best clinical outcome and more durability regarding the case being worked on.

CONCLUSIONS

Within the limitations of the current study, it is possible to conclude that:

1. There was a significant difference in the fracture resistance between the tested materials.
2. ZR and LD showed a significant difference in fracture resistance after being repaired.
3. VE showed no significant difference in fracture resistance after repair.
4. All the tested materials had fracture resistance values greater than the highest reported masticatory forces.

This indicates that they are all capable of withstanding normal intraoral forces.

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Authors' Contribution

Abdulateef MR, Qassim MH, and Hasan NH completed the conceptualization, data curation, formal analysis, methodology, finding acquisition, investigation, resources, software, validation, visualization, writing- original draft, and editing. All authors completed the visualization, review & editing.

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Ethical statement: This study was reviewed and approved by the Ethics Committee of Mosul University (approval code: **H.DM.44/22**). All procedures involving human teeth were conducted following ethical standards, and informed consent was obtained from all patients prior to tooth extraction and use in this research.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

Availability of data and materials: All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declaration of Generative AI and AI-assisted technologies

During the preparation of this work, the authors used grammar to improve the readability of the manuscript. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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فشــل مقاومة الاحمال لأنواع من التيجان الخزفية المُرممة بتقنية ال CAD/CAM بعد تحضــير قناة الجذر

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الملخص

الأهداف: هدفت هذه الدراسة إلى تقييم مقاومة الكسر لتيجان السيراميك المختلفة المصنعة بتقنية CAD/CAM بعد تحضير وإصلاح تجويف الوصول إلى قناة الجذر وفقًا لمعايير موحدة، وذلك باستخدام بروتوكولين ترميميين.

المواد وطرائق العمل: تم تحضير تسعين ضرسًا من الأضراس الأمامية العلوية البشرية المخلوعة لتركيب تيجان تغطي كامل السن، وتم ترميمها باستخدام ثنائي سيليكات الليثيوم (LD)، أو زركونيا رباعية التبلور مثبتة بالإيتريوم (ZR)، أو السيراميك المشــرب بالبوليمر (VE) (ن = 30 لكل مجموعة). قُسّــمت كل مجموعة إلى ثلاث مجموعات فرعية (ن = 10): تيجان سليمة، وتيجان تم إصلاح تجويف الوصول إليها باستخدام طقم إصلاح البورسلين (GC)، وتيجان تم إصلاحها باستخدام الراتنج المركب (Filtek Z350 XT). تم توحيد تجاويف الوصول إلى قناة الجذر باستخدام قالب مخصص، وتم تحضيرها باستخدام مثاقب ماسية مع التبريد بالماء. خضعت العينات لاختبار التحميل الحراري الميكانيكي، ثم تم اختبار كسرها باستخدام جهاز اختبار عالمي. تم تحليل البيانات باستخدام تحليل التباين أحادي الاتجاه واختبار دنكان للمدى المتعدد ($\alpha=0.05$).

النتائج: أظهرت تيجان الزركونيوم أعلى مقاومة للكسر في جميع الحالات (المتوسط للحالة السليمة: 3887.3 نيوتن؛ ترميم باســتخدام GC: 3371.7 نيوتن؛ ترميم باســتخدام الحشــوة المركبة: 2955.3 نيوتن)، تليها تيجان LD (2742 نيوتن؛ 2281.5 نيوتن؛ 1960.2 نيوتن) وتيجان VE (1849.4 نيوتن؛ 1397.8 نيوتن؛ 1281.2 نيوتن). أدى تحضــير منطقة الوصول إلى تقليل مقاومة الكسر بشكل ملحوظ في جميع المواد ($p<0.05$). حقق الترميم باستخدام GC مقاومة كسر أعلى بشكل ملحوظ من الحشوة المركبة في تيجان الزركونيوم وLD، ولكن ليس في تيجان VE. كانت معظم حالات الفشل (60%) غير مواتية، مع غلبة كسور الحدبات المائلة.

الاســتنتاجات: يُضــعف تحضــير مدخل قناة الجذر بشــكل ملحوظ تيجان CAD/CAM بغض النظر عن المادة أو طريقة الترميم، على الرغم من أن جميع التيجان المختبرة (ZR، LD، وVE) حافظت على مقاومة للكســر أعلى من أقصــى قوى المضغ المُسجلة (500-700 نيوتن). أظهرت تيجان الزركونيا أداءً ميكانيكيًا فائقًا، ووفر الترميم القائم على مادة GC استعادة أفضل للقوة في تيجان ZR وLD.

الكلمات المفتاحية: تيجان CAD/CAM، مدخل قناة الجذر، مقاومة الكسر، ثنائي سيليكات الليثيوم، السيراميك المُشرب بالبوليمر، مادة الترميم، الزركونيا.