applied sciences

MDPI

*Article*

# Impact of Various Cavity-Preparation Designs on Fracture Resistance and Failure Mode of CAD/CAM Fabricated Ceramic Inlays and Onlays

**Ali Atef Elkaffas [1,2,*], Abdullah Mohammed Alshehri [1], Ali Robaian Alqahtani [1], Refal Saad Albaijan [3] and Tarek Ahmed Soliman [1]**

[1] Department of Conservative Dental Sciences, College of Dentistry, Prince Sattam Bin Abdulaziz University, Alkharj 11942, Saudi Arabia; am.alshehri@psau.edu.sa (A.M.A.); ali.alqahtani@psau.edu.sa (A.R.A.); t.soliman@psau.edu.sa (T.A.S.)
[2] Operative Dentistry Department, Faculty of Dentistry, Mansoura University, Mansoura 35516, Egypt
[3] Department of Prosthodontics, College of Dentistry, Prince Sattam Bin Abdulaziz University, Alkharj 11942, Saudi Arabia; r.albaijan@psau.edu.sa
* Correspondence: a.elkaffas@psau.edu.sa

**Abstract:** In recent years, CAD/CAM technology has allowed indirect ceramic restorations to become a part of everyday chairside clinical practice. Therefore, the impact of different cavity-preparation designs on the fracture resistance of CAD/CAM fabricated ceramics was assessed in this study. Three designs of cuspal covering (none, palatal, and entire) and two widths of the occlusal isthmus (75% and 100% of the intercuspal distance) were used for the preparation of inlays and onlays to form six groups (n = 10/group). Moreover, thermomechanical cyclic loading was applied to every tooth under a chewing simulator. A universal testing machine was used to measure each group's fracture resistance. The tested specimens were inspected for any signs of fractures and cracks to categorize failure patterns. Thereby, the values of fracture strength showed that there were statistically nonsignificant differences between the tested groups ($p < 0.05$). However, a significant difference ($p = 0.01$) was found between group 1 (inlays) (1950 ± 405) and group 6 (onlays) (3900 ± 770). Type III or type IV fracture modes were seen in the majority of the specimens. In conclusion, inlays and onlays made of zirconia using CAD/CAM technology were deemed reliable for restoring premolars, irrespective of the cavity-preparation design, except for inlays with a 75% intercuspal distance.

**Keywords:** ceramics; inlays; onlays; zirconia; fracture resistance

check for updates

**Citation:** Elkaffas, A.A.; Alshehri, A.M.; Alqahtani, A.R.; Albaijan, R.S.; Soliman, T.A. Impact of Various Cavity-Preparation Designs on Fracture Resistance and Failure Mode of CAD/CAM Fabricated Ceramic Inlays and Onlays. *Appl. Sci.* **2024**, *14*, 3816. https://doi.org/10.3390/app14093816

Academic Editors: Anca Jivănescu and Diana Dudea

Received: 8 March 2024
Revised: 31 March 2024
Accepted: 7 April 2024
Published: 30 April 2024

**Copyright:** © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

## 1. Introduction

Indirect ceramic restorations have become a regular feature of chairside clinical practice in recent years thanks to advancements in CAD/CAM technology. In addition to meeting the aesthetic needs of the patient, these restorations provide clinical confidence because of their exceptional material strength, marginal fit, contour, and anatomy. A variety of block-shaped ceramic materials that can be milled using CAD/CAM technology have been introduced to the clinical field of restorative dentistry because of these advancements [1–3].

Dental restoration longevity is estimated based on several parameters, some related to the material and others patient- or dentist-specific. Polymerization shrinkage is known to cause problems such as deboning and fracturing, yet direct composite resin restorations are still commonly performed. Indirect restorations are, therefore, used to solve these issues [4].

Lately, there has been a noticeable shift in favor of using CAD/CAM technology to create indirect restorations [5]. One advantage of this technology is a reduction in the frequency of production errors [5]. This is achieved by eliminating some more complex laboratory processing procedures and decreasing the time and effort needed by both patient and dentist [6]. Many materials, including zirconia, can be used to provide indirect restorations for posterior teeth. These materials are biocompatible, long-lasting, aesthetically pleasing, and resistant to fatigue [7].

For posterior teeth with significant cavities caused by caries, onlay restorations are a desirable treatment option because they decrease tooth tissue loss and offer preferable aesthetics [8,9]. Onlays also offer beneficial stress distribution by covering multiple tooth cusps, decreasing the chance of tooth and/or restoration fracture [10]. The degree to which indirect ceramic restorations resist fracture is one of the most crucial factors in determining their efficacy [11].

Clinical fracture or failure of zirconia ceramic restorations is influenced by various parameters: the mechanical characteristics of the restoration, the width of the isthmus, the depth of preparation, the morphology of internal line angles, and other aspects of cavity geometry [12,13].

If a tooth's fracture resistance is compromised during cavity preparation, it is challenging to restore [14]. Dentists have been advised to use the preparation design that provides the highest resistance to fracture. Fracture-resistance tests have been used to measure the forces that may cause such restorations to fracture. However, research on the effects of preparation design on the stress distribution and fracture resistance of tooth structures restored with partial ceramic crowns has produced confusing and inconsistent results [14].

Restorations performed with an indirect approach employing a CAD/CAM system may have been selected in cases where there has been a greater loss of tooth structure, according to Vianna et al. [15]. Many research and papers have addressed the isthmus width in direct restoration, even though it is crucial for the preservation and integrity of the restoration and teeth [14–16].

Since its impact on indirect restoration is still unknown, the purpose of this study is to investigate how isthmus width affects fracture resistance and failure modes in premolar teeth by investigating its effects in various cavity-preparation designs for zirconia ceramic inlays and onlays made with CAD/CAM technology [17]. The null hypothesis stated that the fracture resistance and mode of failure of premolars restored with zirconia inlays and onlays are not significantly impacted by variations in cavity-preparation designs.

## 2. Materials and Methods

### *2.1. Materials Utilized in the Current Study*

A. IPS e.max ZirCAD Prime (Ivoclar Vivadent, Amherst, NY, USA).

B. G-CEM® CAPSULE (Hasunuma-cho, Itabashi-ku, Tokyo, Japan).

Table 1 includes a list of the restorative materials together with information about each one, such as the manufacturer, composition, application methods, brand names, and specifications. Table 2 explains the application methods and luting resin cement system employed in this research.

**Table 1.** Restorative materials used in the present study.

| Material | Description | Composition | | Manufacturer | Batch Number | Step by Step Guideline |
|---|---|---|---|---|---|---|
| IPS e.max ZirCAD Prime | Yttrium-stabilized zirconium oxide (Hybrid 3Y-TZP and 5Y-TZP). | Matrix | Matrix degree | Vivadent, Ivoclar, Amherst, NY, USA | X41232 | 1. $Al_2O_3$ has been blasted at 1 bar on the internal surface of every onlay, ranging from 25 to 70 µm.<br>2. Then treated with Monobond N for 60 s.<br>3. Then bonded by G-Cem Capsule. |
| | | $ZrO_2$ | >87 wt.% | | | |
| | | $Y_2O_3$ | 4.5–7% | | | |
| | | $HfO_2$ | ≤5% | | | |
| | | $Al_2O_3$ | 0.03–0.35% | | | |

**Table 2.** The luting resin composite system used in this study.

| Material | Description | Manufacturer | Batch Number | Steps of Application |
|---|---|---|---|---|
| Try-In Paste | Glycerin, mineral fillers, and dyes. | Schaan, Liechtenstein, Ivoclar Vivadent | 7402213 | 1. First the paste was spread on the fitting surface of ceramic restoration.<br>2. Then, the ceramic was positioned in the correct position. |
| Liquid Strip | Glycerin gel. | | 740122 | 1. Spread the coating throughout the whole margin prior to light polymerization.<br>2. Apply a light cure for 10 s on each part.<br>3. Then rinse and dry. |
| Monobond N | Ethanol, 3-trimethoxysilyl propyl, methacrylate silane, methacrylated phosphoric acid ester, sulfide methacrylate. | | Z01CTK | 1. With a brush and a gentle scrubbing motion, apply one layer of the bond.<br>2. Let 5 s for a gentle air drying.<br>3. Light curing for 10 s. |
| G-Cem Capsule | Powder and liquid: initiator, pigment, silica powder, dimethacrylate, phosphoric acid ester, fluoroaluminosilicate glass, initiator, trimellitic acid, monomer, water, urethane dimethacrylate, stabilizer 65–70%wt, 4-methacryloxyethyl. | Hasunuma-cho Itabashi-ku Tokyo, Japan | 129921 | 1. First the capsule is activated.<br>2. Then mix for 10 s using an amalgamator.<br>3. Spread cement within the ceramic.<br>4. Secure the ceramic.<br>5. Brush excess cement.<br>6. Light cure each surface for 40 s. |

### *2.2. Study Design*

Two criteria were used in this scientific study to evaluate the ceramic onlays and inlays made with CAD/CAM systems in terms of their fracture resistance.

A. Type of restoration (inlay or onlay).

B. Intercuspal distance (ICD).

### *2.3. Specimens' Preparation*

This study used sixty extracted human premolars that were free of cavities and flaws to conduct an in vitro investigation. These teeth were taken out of the Oral and Maxillofacial Surgery clinic due to periodontal disease. The Dental College's Ethical Committee authorized the infection control procedures for tooth collection. A hand scaler was then used to remove any remaining soft tissue and calculus (Zeffiro, Lascod, Florence, Italy). Next, the extracted teeth were cleaned using a rubber cup filled with a fine pumice water slurry, and then they were examined under a stereomicroscope (Olympus model SZ-PT, Tokyo, Japan) for indications of damage.

The teeth were cleaned and disinfected with a 1% Chloramine-T solution for the following three days. The study only comprised teeth that were unrestored, noncarious, and in their entirety. A stereomicroscope (Olympus model SZ-PT, Tokyo, Japan) was used to inspect the teeth. To prevent dehydration, the teeth were then maintained in distilled water and replaced every five days during the study. They were only taken out for the test procedure.

The teeth's roots were then buried up to 2 mm beneath the CEJ inside a PVC ring, which is 1.4 $\times$ 2 cm and cylindrical. It was made of vinyl chloride and auto-polymerizing acrylic resin (Acrostone, Cairo, Egypt). This was performed to stimulate the periodontal ligaments. Each tooth was removed from the cylinder it had been stored in once the acrylic resin had had enough time to dry.

To make the impression, polyether impression material (Soft Impregum by 3M ESPE, St. Paul, MN, USA) was injected into the acrylic resin's alveolus. This was accomplished by slicing away the extra polyether material with a scalpel blade, leaving a gap of 0.2 to 0.3 mm, which is nearly equal to the traditional thickness of the periodontal ligament.

A high-speed handpiece (Sirona T3, Ballantyne Corporate Pl, Charlotte, NC, USA) was used to prepare the inlay and onlay cavities. Coarse diamond and finishing diamond burs (Inlay Preparation Set 4263; Komet, Lemgo, Germany) and (Onlay prep-set, Intensiv, Viaganello-Lugano, Switzerland) were used to accomplish this. To standardize this experiment, each bur was replaced after four dental preparations. To ensure standardization of the preparation designs of each experimental group, the handpiece was mounted to a parallelometer (Paraskop M, Model No. 26060; Bego, Bremen, Germany). The specifications included a pulpal floor depth of 2.5 mm from the occlusal surface, 90° cavosurface angles, a 6° convergence angle toward the occlusal aspect, rounded internal line angles, and no bevels or undercuts.

## 2.4. Preparation Procedure

For the preparatory process, each group (n = 10) had a unique approach (Figure 1) as follows:

1. Group 1 inlays had a 75% ICD cavity width from the buccal to the palatal cusp tips.
2. Group 2 inlays were 100% of the ICD's width.
3. Group 3 onlays had a 75% ICD width and a functional cusp decrease of 2.0 mm in the palatal cusp.
4. Group 4 onlays had a 100% ICD width and a functional cusp decrease of 2.0 mm in the palatal cusp.
5. Group 5 had a 75% width of ICD, a 2.0 mm functional palatal cusp reduction, and a 1.5 mm nonfunctional buccal cusp reduction.
6. Group 6 had a 100% width of ICD, a 2.0 mm functional palatal cusp reduction, and a 1.5 mm nonfunctional buccal cusp reduction.

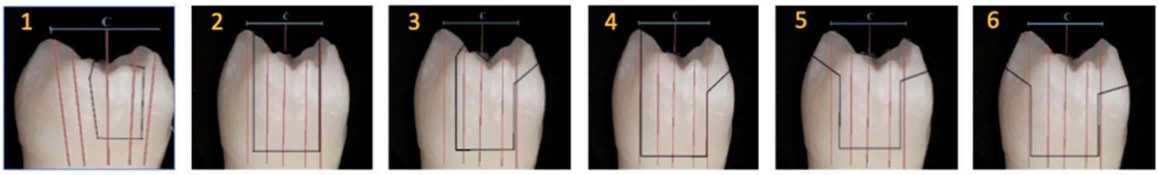


**Figure 1.** Preparation designs of different experimental groups (c = intercuspal distance): inlay with 75% of ICD restored (**1**), inlay with 100% ICD restored (**2**), onlay with 75% of ICD restored covering the lingual cusp (**3**), onlay with 100% of ICD restored covering the lingual cusp (**4**), onlay with 75% of ICD restored covering all cusps (**5**), and onlay with 100% ICD restored covering all cusps (**6**).

## 2.5. Digital Impression

Sixty preparations were scanned using an intraoral scanning system (Cerec Omnicam, Dentsply Sirona, Charlotte, NC, USA). Sixty onlays and inlays were also designed and milled from IPS e.max ZirCAD prime blocks using the CEREC system.

## 2.6. Fabrication of Inlay and Onlay Restorations

The same technician used the same procedure and the manufacturer's instructions to create each restoration. The indirect restorations were all created using the CAD/CAM technique. The samples were scanned both before and after processing using intraoral scanning. The software generated indirect restorations that returned the generated samples to their initial state by utilizing the Biogeneric Copy function of the Cerec software version

5.1. Blocks of IPS e.max ZirCAD Prime (Ivoclar Vivadent, Amherst, NY, USA) were used to mill the restorations following the manufacturer's instructions.

Following the manufacturer's instructions, the restorations were sintered in a special furnace (Programat S2 Furnace; Ivoclar Vivadent), and glaze paste (IPS e.max CAD Crystal/Glaze spray; Ivoclar Vivadent) was used to glaze them. In addition to being cleaned with detergent under running water, the samples were ultrasonically cleaned in water for 10 min.

### 2.7. Try-In of Onlay and Inlay Restorations

Every procedure was completed following the manufacturer's instructions. Throughout the restoration procedure, the try-in paste was utilized to make sure the restorations had a proper marginal fit. Afterward, the cavity was cleared of any remaining try-in paste. Each onlay and inlay's internal surface was sandblasted to clear any dirt following the try-in process. Lastly, we smoothed out the cement lines with finishing and polishing strips (OptraPol, Ivoclar Vivadent).

### 2.8. Cementation

Following the completion of the try-in procedures, the restorations were bonded to the teeth using a dual-curing luting resin cement (G-CEM® CAPSULE, Hasunuma-cho, Itabashi-ku, Tokyo, Japan). We thoroughly rinsed restorations created with IPS e.max ZirCAD prime with water drizzle and let them air dry. Following a 60 s pause, a thin amount of priming agent Monobond N (Vivadent, Ivoclar, Schaan, Liechtenstein) was applied to each zircon's fitting surface. An intense jet of air was used to scatter any leftover excess. To ensure uniformity throughout our investigation, every specimen underwent identical procedures. The restoration was finger-pressed after the cement had been placed on the surface.

After removing the extra cement with an excavator, a liquid strip was applied along the restoration margins to prevent the polymerization process from creating an oxygen-inhibition layer. Using a liquid strip, each specimen underwent 40 s of light polymerization in each direction.

To obtain a smooth surface, flexible discs (Sof-Lex XT Pop On, 3M ESPE) were utilized throughout the cement border finishing process. The cement margins were successfully finished by using finishing and polishing discs in the required order (coarse, medium, fine, and superfine). Following the cementation of the restorations, each specimen was maintained in distilled water for a full day at $37 \pm 1$ °C.

### 2.9. Thermomechanical Cyclic Loading (Chewing Simulator)

Using a specially designed cone-shaped stainless-steel bar with a rounded tip, mechanical cycles of axial compressive loads were applied using a masticatory simulator (CS-4.4 SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). This bar represented a 60 mm/s vertical movement of 2.5 mm. The central fossa of every restoration was subjected to a force of fifty newtons (N) by the simulator.

The chewing simulator was modified to enable temperature cycles using the thermocycling device (TC-3; SD Mechatronik GmbH, FeldkirchenWesterham, Germany). Thermocycling took place in distilled water at temperatures between 5° and 55 °C for 30 s.

A total of 120,000 mechanical and 5000 heat cycles were applied to each restoration. The simulations roughly mirrored a six-month oral service period. Then, to make sure the restoration had not been damaged, each piece was checked using a stereomicroscope (Nikon SMZ-10; Nikon Corporation, Tokyo, Japan) with a 40× magnification.

### 2.10. Compressive Fracture Resistance Test

Each specimen was forced with a compressive force using a universal testing machine (Instron 3345, Canton, MA, USA) equipped with a 10 kN load cell. A metal sphere with an 8 mm diameter and a crosshead speed of 0.1 mm per minute was used to load each specimen. The premolars' central fossa was where the force was administered. To prevent a localized concentration of stress, a 2 mm thick urethane rubber sheet was positioned between the specimen and the metal sphere. The force value (N) required to produce the initial fracture was recorded.

### 2.11. Failure Mode

The following categorization method was used to classify the specimens based on the mode of failure after they were inspected for any signs of cracks or cohesive or adhesive failures: (I) ceramic extensive, (II) ceramic cohesive failure, (III) fracture within the ceramic and tooth structure while the root is preserved, (IV) longitudinal fracture of ceramic and tooth structure while the root is involved. Using a stereomicroscope (Nikon SMZ-10; Nikon Corporation, Tokyo, Japan) at a 40× magnification, the fractured surface of each specimen was examined.

### 2.12. Statistical Analysis

The Shapiro–Wilk, post hoc Tukey, and one-way ANOVA tests were used to statistically analyze the data to determine the material's resistance to fracture. To determine if the force distribution was uniform under the most severe compression conditions, the Shapiro–Wilk test was used. A statistically significant correlation was shown with a value of $p < 0.05$.

## 3. Results

The Shapiro–Wilk confidence test was used to examine the fracture force values, and the results showed that all group data were normally distributed ($p < 0.05$). A one-way analysis of variance (ANOVA) was utilized, together with a post hoc Tukey test, to compare more than two distinct sets of parametric data. Therefore, statistical significance was defined as a $p$ value of less than 0.05.

Statistically nonsignificant differences ($p < 0.05$) were found between experimental groups using one-way ANOVA within force at the maximal compressive force (Pascal). A post hoc analysis of the data revealed a significant difference ($p = 0.01$) only between groups 1 and 6. Table 3 illustrates that there were negligible differences found in the comparisons between the other groups (1950 ± 405, 2522 ± 789, 2590 ± 930, 2130 ± 321, 2410 ± 523, and 2900 ± 770, respectively).

**Table 3.** Comparing the forces in each group at the maximal compressive stress (Pascal).

| | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | ANOVA *p* Value |
|---|---|---|---|---|---|---|---|
| Fracture Resistance Mean ± SD | 1950 ± 405 | 2522 ± 789 | 2590 ± 930 | 2130 ± 321 | 2410 ± 523 | 2900 ± 770 | 0.04 |
| Post hoc Tukey | | P1 = 0.42 | P1 = 0.34<br>P2 = 0.94 | P1 = 0.91<br>P2 = 0.93<br>P3 = 0.91 | P1 = 0.65<br>P2 = 0.99<br>P3 = 0.99<br>P4 = 0.99 | P1 = 0.01 *<br>P2 = 0.54<br>P3 = 0.59<br>P4 = 0.12<br>P5 = 0.29 | |

Data expressed as mean ± SD; SD: standard deviation; P: probability *: significance < 0.05. The test used one-way ANOVA followed by post hoc Tukey. P1: significance vs. group 1, P2: significance vs. group 2, P3: significance vs. group 3, P4: significance vs. group 4, P5: significance vs. group 5.

Table 4 lists the restored premolars' failure scenarios following the load-to-failure test. Most specimens showed either type III or IV fracture mode, which denotes failure within the ceramic materials and coronal portion of the underlying tooth structure or longitudinal catastrophic failure that extends into the root. The occlusal surface's contact loading point was the major fracture origin. The deeper cervical region of the restoration and the tooth structure were subsequently affected by the crack, while the groups with complete cusp coverage primarily displayed bulk fractures of zirconia restorations and coronal portions of prepared premolars. Furthermore, the groups with palatal cusp coverage displayed longitudinal root-involved fractures and residual buccal cusp sections.

**Table 4.** The failure mode of experimental groups.

| Preparation Design Group | Mode of Fracture (Number of Specimens) | | | |
|---|---|---|---|---|
| | I | II | III | IV |
| 1 | - | - | 5 | 5 |
| 2 | - | - | 6 | 4 |
| 3 | - | - | 4 | 6 |
| 4 | - | - | 2 | 8 |
| 5 | - | 1 | 7 | 2 |
| 6 | 1 | - | 8 | 1 |

I: Ceramic extensive failure; II: ceramic cohesive failure; III: fracture within the ceramic and tooth structure while the root is preserved; IV: longitudinal fracture of ceramic and tooth structure while the root is involved.

## 4. Discussion

The outcome measure employed in the investigation was the extent to which each preparation's design could resist fracturing. The results show that, excluding inlays with a 75% ICD, the fracture resistance between the various experimental groups did not noticeably differ. Therefore, it was possible to partially reject the null hypothesis, that the fracture resistance and mode of failure of premolars restored with zirconia inlays and onlays are not significantly impacted by variations in cavity-preparation designs.

The common clinical concern of broken and cracked teeth is approximately the third-most prevalent cause of tooth loss. Breakage and cusp loss can result from large restorations and severe carious lesions [18]. Regarding preliminary designs for preparations, although opinions on the best way to lessen cuspal fracture differ, there is a definite correlation between fracture strength and the amount of lost dental tissue [19].

The mentioned result is consistent with what Morin et al. [20], St-Georges et al. [21], and, most significantly, Mondelli et al. [18] found: that the behavior of teeth whose preparation involved a greater removal of the dental structure affected fracture resistance. Even when oxides are added for reinforcement, indirect ceramic restorations nonetheless have a high modulus of elasticity and a large concentration of stress within the main body of the restoration [22–24].

The study's findings also support Stappert et al.'s [22] call to further investigate constraints associated with the design of inlay cavities. Those authors examined the fracture resistance of natural teeth, inlays, and onlays and found that none of the groups that underwent testing had significantly different fracture resistances [25–27].

Furthermore, the depth of preparation and the width of the isthmus have an impact on the cuspal deflection and, consequently, the fracture strength [18,28]. To maintain dental tissue, it is advised to employ a preparation that is defect-oriented [29]. Despite this, it was suggested that superior clinical studies be conducted to confirm the results obtained in the lab [30].

A noteworthy observation is that group 6, one of the study's sample groups, showed the best fracture resistance results compared to the other five groups. This group's onlays had palatal functional cusp reductions of 2.0 mm and buccal nonfunctional cusp reductions of 1.5 mm This finding indicates an additional benefit that the planned design of ceramic onlays may provide. Additionally, the production of onlays with 100% ICD covering all cusps is associated with a decreased risk of ceramic fracture, based on the logistic extrapolation of the data found in this study.

However, the results of this study indicate that there is no significant difference in the fracture strength of ceramic restorations made with and without different cavity-preparation designs. This means that different designs did not affect the fracture strength of the restorations. This is a preliminary decision based on the results of the clinical practitioner. If it is decided that an indirect restoration is the best course of action, the clinician will choose the geometry of the cavity preparation [31,32].

However, because there is a chance of obtaining false positives when implementing our findings in clinical settings, caution is advised. Before specific preparation designing protocols with a 100% cusp reduction are routinely prescribed in patients, further research is advised.

The maximal axial biting forces in males and females who are biting voluntarily have been reported to be much less than the mean fracture strength values of this experiment (1950–2900) N (480–788 N). The voluntary maximum axial biting force is more than the typical range of masticatory forces, which is 17 N to 450 N. People who have bruxism frequently produce involuntary forces between 400 and 1100 N [33].

However, while chewing involves a combination of axial and lateral pressures and movements, in vitro results are based on axial loading. This is in line with the investigation's conclusions, which state that a fracture resistance of greater than 1100 N is necessary to maintain adequate clinical performance [34]. However, the chewing simulator was useful in the current study to simulate oral conditions.

Furthermore, the formation and propagation of cracks might cause restorations to shatter. This is particularly crucial to remember while working with restorations made of ceramic materials [17]. With larger preparations, the remaining tooth structure becomes weaker and there is greater cusp bending than ever before due to occlusal stresses. Some researchers feel that onlays with cuspal covering are the best restoration for teeth that have undergone extensive Class II MOD preparations because they may assist in avoiding cuspal displacement under load [35].

The newest generation of zirconia restorative material IPS e.max ZirCAD Prime used in the current study is the future of all-ceramic restorations. This revolutionary material ensures exceptional aesthetics and provides a complete solution for both dental technicians and clinicians. The unique "gradient technology" allows two zirconium oxide raw materials, 3Y-TZP and 5Y-TZP, to be combined, offering the strength of 3Y-TZP and the aesthetics of 5Y-TZP [36]. Regarding tooth complex repair, zirconia-based onlays perform better under high compressive pressures than lithium-disilicate-based onlays, according to Saridag S. et al. [17,37].

Because resin cement, which is used in adhesive restorations, is elastic, it tends to flex under stress, strengthening the material's resistance to fracture. Thus, the key to successful ceramic inlay and onlay placement is creating an adhesive tooth–ceramic contact that is uncompromised [38].

Numerous surface roughening techniques have been developed to achieve micromechanical interlocking between zirconia and resin cement, including sandblasting, laser etching, selective infiltration etching, and nanostructured alumina coating. For zirconia ceramics, sandblasting is the most recommended surface roughening technique [39]. Through the formation of microcracks on the zirconia surface, this technique can degrade the ceramic while increasing surface energy and wettability [39]. However, resin luting agents heal the minor surface flaws created by sandblasting and strengthen the ceramic. Mechanical adhesion achieved by surface roughening is not enough to provide a durable bond between zirconia and resin cement. Thus, adhesive strategies combining surface roughening procedures and chemical bonding, which involve using various primers and resin cement, were utilized in the current study [40].

All studied groups' failure patterns revealed that type III or IV catastrophic fractures, including those involving the underlying tooth structure, predominated. Premolars treated with zirconia onlays of standard preparation (2 mm width of isthmus and reduction in palatal and buccal cusps by 2 mm) typically displayed catastrophic fractures involving tooth structure, according to a recent publication by Guess et al. [41].

This may be attributed to the high modulus of the elasticity of zirconia and its minimal capacity to deform, making it susceptible to fatigue-induced fracture. However, the supporting dentin in this study exposed during cavity preparation has a low modulus of elasticity. Therefore, identifying adequate preparation designs showing high fracture resistance is essential to the longevity of zirconia restorations [42]. Nevertheless, the cushioning effect of the adhesive resin cement alone could not absorb the increased stress caused by external loading, which ultimately resulted in the cohesive fracture of ceramic restorations, including the roots. As a result of loading, the ceramic is more susceptible to fracture since its high flexural strength is formed at the dentin–ceramic interface [42]

In summary, a laboratory study cannot duplicate the foundations of the oral environment and cannot solve the challenges of separating the clinical operative field when treating posterior tooth preparations. Therefore, to validate laboratory data and support recently established techniques, randomized controlled clinical studies with sufficient recall intervals are needed.

## 5. Conclusions

Inlays and onlays made of zirconia using CAD/CAM technology were deemed reliable for restoring premolars, irrespective of the cavity-preparation design, except for inlays with a 75% ICD. Clinical relevance studies using a range of preparation designs for CAD/CAM ceramic indirect restorations will be necessary in the future.

### *Clinical Relevance*

The restoration of premolar teeth with MOD cavities may be possible using ceramic inlays and onlays with different preparation patterns.

**Author Contributions:** Conceptualization, A.A.E., A.M.A. and T.A.S.; Methodology, A.A.E. and R.S.A.; Formal analysis, A.R.A. and T.A.S.; Investigation, A.A.E. and A.M.A.; Writing—original draft, A.M.A.; Writing—review & editing, A.R.A. and R.S.A. All authors have read and agreed to the published version of the manuscript.

**Funding:** The study was supported via funding from Prince Sattam bin Abdulaziz University project number (PSAU/2024/R/1445).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Sadowsky, S.J. An overview of treatment considerations for esthetic restorations: A review of the literature. *J. Prosthet. Dent.* **2006**, *96*, 433–442. [CrossRef] [PubMed]
2. Tagtekin, D.A.; Ozyoney, G.; Yanikoglu, F. Two-year clinical evaluation of IPS Empress II ceramic onlays/inlays. *Oper. Dent.* **2009**, *34*, 369–378. [CrossRef] [PubMed]
3. Lopez-Suarez, C.; Tobar, C.; Sola-Ruiz, M.F.; Pelaez, J.; Suarez, M.J. Effect of thermomechanical and static loading on the load to fracture of metal-ceramic, monolithic, and veneered zirconia posterior fixed partial dentures. *J. Prosthodont.* **2019**, *28*, 171–178. [CrossRef] [PubMed]
4. Denry, I.; Kelly, J.R. State of the art of zirconia for dental applications. *Dent. Mater.* **2008**, *24*, 299–307. [CrossRef] [PubMed]
5. Kang, S.Y.; Park, J.H.; Kim, J.H.; Kim, W.C. Three-dimensional trueness analysis of ceramic crowns fabricated using a chairside computer-aided design/manufacturing system: An in vitro study. *J. Prosthodont. Res.* **2020**, *64*, 152–158. [CrossRef] [PubMed]
6. Thongthammachat, S.; Moore, B.K.; Barco, M.T.; Hovijitra, S.; Brown, D.T. Dimensional accuracy of dental casts: Influence of tray material, impression material, and time. *J. Prosthodont.* **2002**, *11*, 98–108. [CrossRef]
7. Homaei, E.; Farhangdoost, K.; Tsoi, J.K.H.; Matinlinna, J.P.; Pow, E.H. Static and fatigue mechanical behavior of three dental CAD/CAM ceramics. *J. Mech. Behav. Biomed. Mater.* **2016**, *59*, 304–313. [CrossRef] [PubMed]
8. Dejak, B.; Mlotkowski, A.; Romanowicz, M. Strength estimation of different designs of ceramic inlays and onlays in molars based on the Tsai-Wu failure criterion. *J. Prosthet. Dent.* **2007**, *98*, 89–100. [CrossRef]
9. Yamanel, K.; Caglar, A.; Gülsahi, K.; Ozden, U.A. Effects of different ceramic and composite materials on stress distribution in inlay and onlay cavities: 3-D finite element analysis. *Dent. Mater. J.* **2009**, *28*, 661–670. [CrossRef]

10. Magne, P.; Belser, U.C. Porcelain versus composite inlays/onlays: Effects of mechanical loads on stress distribution, adhesion, and crown flexure. *Int. J. Periodontics Restor. Dent.* **2003**, *23*, 543–555.
11. Homsy, F.; Eid, R.; El Ghoul, W.; Chidiac, J. Considerations for Altering Preparation Designs of Porcelain Inlay/Onlay Restorations for Nonvital Teeth. *J. Prosthodont.* **2015**, *24*, 457–462. [CrossRef] [PubMed]
12. Soares, C.; Martins, L.; Fonseca, R.; Correr-Sobrinho, L.; Fernandes Neto, A. Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations. *J. Prosthet. Dent.* **2006**, *95*, 421–429. [CrossRef]
13. Liu, X.; Fok, A.; Li, H. Influence of restorative material and proximal cavity design on the fracture resistance of MOD inlay restoration. *Dent. Mater.* **2014**, *30*, 327–333. [CrossRef]
14. Federlin, M.; Sipos, C.; Hiller, K.; Thonemann, B.; Schmalz, G. Partial ceramic crowns. Influence of preparation design and luting material on margin integrity a scanning electron microscopic study. *Clin. Oral. Investig.* **2005**, *9*, 8–17. [CrossRef]
15. Vianna, A.; Prado, C.; Bicalho, A.; Pereira, R.; Neves, F. Effect of cavity preparation design and ceramic type on the stress distribution, strain and fracture resistance of CAD/CAM onlays in molars. *J. Appl. Oral. Sci.* **2018**, *26*, 2018–2024. [CrossRef]
16. Anand, V.; Kavitha, C.; Subbarao, C. Effect of Cavity Design on the Strength of Direct Posterior Composite Restorations: An Empirical and FEM Analysis. *Int. J. Dent.* **2011**, *2011*, 214–751. [CrossRef]
17. Saridag, S.; Sevimay, M.; Pekkan, G.Ü. Fracture resistance of teeth restored with all-ceramic inlays and onlays: An in vitro study. *Oper. Dent.* **2013**, *38*, 626–634. [CrossRef]
18. Mondelli, J.; Steagall, L.; Ishikiriama, A.; de Lima Navarro, M.; Soares, F. Fracture strength of human teeth with cavity preparations. *J. Prosthet. Dent.* **1980**, *43*, 419–422. [CrossRef]
19. Sheth, J.; Fuller, J.; Jensen, M. Cuspal deformation and fracture resistance of teeth with dentin adhesives and composites. *J. Prosthet. Dent.* **1988**, *60*, 560–569. [CrossRef]
20. Morin, D.; DeLong, R.; Douglas, W. Cusp reinforcement by the acid-etch technique. *J. Dent. Res.* **1984**, *63*, 1075–1080. [CrossRef]
21. St-Georges, A.; Sturdevant, J.; Swift, E.; Thompson, J. Fracture resistance of prepared teeth restored with bonded inlay restorations. *J. Prosthet. Dent.* **2003**, *89*, 551–557. [CrossRef]
22. Stappert, C.; Guess, P.; Chitmongkolsuk, S.; Gerds, T.; Strub, J. Partial coverage restoration systems on molars--comparison of failure load after exposure to a mastication simulator. *J. Oral. Rehab.* **2006**, *33*, 698–705. [CrossRef] [PubMed]
23. Hondrum, S. A review of the strength properties of dental ceramics. *J. Prosthet. Dent.* **1992**, *67*, 859–865. [CrossRef]
24. Kelly, J.; Nishimura, I.; Campbell, S. Ceramics in dentistry: Historical roots and current perspectives. *J. Prosthet Dent.* **1996**, *75*, 18–32. [CrossRef] [PubMed]
25. Eakle, W.; Staninec, M. Effect of bonded gold inlays on fracture resistance of teeth. *Quintessence Int.* **1992**, *23*, 421–425. [PubMed]
26. Borges, G.; Sophr, A.; de Goes, M.F.; Sobrinho, L.; Chan, D. Effect of etching and airborne particle abrasion on the microstructure of different dental ceramics. *J. Prosthet. Dent.* **2003**, *89*, 479–488. [CrossRef]
27. Roggendorf, M.; Krämer, N.; Dippold, C.; Vosen, V.; Naumann, M. Effect of proximal box elevation with resin composite on marginal quality of resin composite inlays in vitro. *J. Dent.* **2012**, *40*, 1068–1073. [CrossRef] [PubMed]
28. Magne, P.; Belser, U.C. *Bonded Porcelain Restorations in the Anterior Dentition: A Biomimetic Approach*; Quintessence International: Batavia, IL, USA, 2002; pp. 45–150.
29. Manhart, J.; Chen, H.; Hamm, G.; Hickel, R. Buonocore Memorial Lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. *Oper. Dent.* **2004**, *29*, 481–508. [PubMed]
30. Soares, C.; Martins, L.; Pfeifer, J.; Giannini, M. Fracture resistance of teeth restored with indirect-composite and ceramic inlay systems. *Quintessence Int.* **2004**, *35*, 281–286. [PubMed]
31. Taha, D.; Abdel-Samad, A.; Mahmoud, S. Fracture resistance of maxillary premolars with class II MOD cavities restored with Ormocer, Nanofilled, and Nanoceramic composite restorative systems. *Quintessence Int.* **2011**, *42*, 579–587.
32. Esquivel-Upshaw, J.; Anusavice, K. Ceramic design concepts based on stress distribution analysis. *Compend. Contin. Educ. Dent.* **2000**, *21*, 649–656.
33. Aydın, B.; Pamir, T.; Baltaci, A.; Orman, M.; Turk, T. Effect of storage solutions on microhardness of crown enamel and dentin. *Eur. J. Dent.* **2015**, *9*, 262–266. [CrossRef] [PubMed]
34. El Ghoul, W.; Özcan, M.; Silwadi, M.; Salameh, Z. Fracture resistance and failure modes of endocrowns manufactured with different CAD/CAM materials under axial and lateral loading. *J. Esthet. Restor. Dent.* **2019**, *31*, 378–387. [CrossRef] [PubMed]
35. Christensen, G. Longevity of posterior tooth dental restorations. *J. Am. Dent. Assoc.* **2005**, *136*, 201–203. [CrossRef] [PubMed]
36. Singhal, S. IPS e. max®ZirCAD®Prime: A new era in dental ceramics. *Esthet. Dent.* **2020**, *1*, 34–37.
37. Shelar, P.; Abdolvand, H.; Butler, S. On the behaviour of zirconia-based dental materials: A review. *J. Mech. Behav. Biomed. Mater.* **2021**, *124*, 104–861. [CrossRef] [PubMed]
38. Burke, F.; Wilson, N.; Watts, D. The effect of cavity wall tapers on fracture resistance of teeth restored with resin composite inlays. *Oper. Dent.* **1993**, *18*, 230–236.
39. Zandsparsa, R.; Talua, N.A.; Finkelman, M.D.; Schaus, S.E. An in vitro comparison of shear bond strength of zirconia to enamel using different surface treatments. *J. Prosthodont.* **2013**, *23*, 117–123. [CrossRef] [PubMed]
40. Xie, H.; Chen, C.; Dai, W.; Chen, G.; Zhang, F. In vitro short-term bonding performance of zirconia treated with hot acid etching and primer conditioning. *Dental. Mater. J.* **2013**, *32*, 928–938. [CrossRef]

41. Guess, P.C.; Schultheis, S.; Wolkewitz, M. Influence of preparation design and ceramic thicknesses on fracture resistance and failure modes of premolar partial coverage restorations. *J. Prosthet. Dent.* **2013**, *110*, 264–273. [CrossRef]
42. Yoon, H.I.; Sohn, P.J.; Jin, S.; Elani, H.; Lee, S.J. Fracture resistance of CAD/CAM-fabricated lithium disilicate MOD inlays and onlays with various cavity preparation designs. *J. Prosthodont.* **2019**, *28*, e524–e529. [CrossRef] [PubMed]

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.