# Do different Cavity Preparation Designs Influence Fracture Resistance of CAD/CAM Fabricated Ceramic Inlay and Onlay?

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ORIGINAL ARTICLE

# Do Different Cavity Preparation Designs Influence Fracture Resistance of Computer-aided Design/Computer-aided Manufacturing Fabricated Ceramic Inlay and Onlay?

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**Abstract**

*Objectives*: **This study evaluated the impact of various cavity preparation designs on fracture resistance of computer-aided design/computer-aided manufacturing ceramic inlays and onlays.**

*Patients and methods*: **A total of 48 teeth were randomly assigned to six groups (n = 8) (group A) inlays with 75 % width of the inter-cuspal distance (ICD, buccal cusp tip-to-palatal cusp tip), (group B) inlays with 100 % width of the ICD, (group C) onlays that had a palatal cusp reduction of 2.0 mm (functional cusp) and 75 % width of ICD, (group D) had a palatal cusp reduction of 2.0 mm (functional cusp) with 100 % width of ICD, (group E) had a palatal cusp reduction of 2.0 mm (functional cusp) and a buccal cusp reduction of 1.5 mm (nonfunctional cusp) and 75 % width of ICD, and (group F) had palatal cusp reduction of 2.0 mm (functional cusp) and had buccal cusp reduction of 1.5 mm (nonfunctional cusp) and 100 % width of ICD. The fracture resistance of each group was measured using a universal testing machine. Data were statistically analyzed using the Shapiro−Wilk, one-way analysis of variance, and post-hoc Tukey tests.**

*Results*: **One-way analysis of variance revealed statistically non-significant differences among the tested groups at ($P < 0.05$), however significant difference was detected between group A (1857 ± 511) and F (3070 ± 804) ($P = 0.01$).**

*Conclusions*: **The various types of preparation designs had no significant difference in fracture resistance except for inlays with 75 % width of ICD.**

*Keywords:* Fracture resistance, Computer-aided design/computer-aided manufacturing, Inlays, Ceramic, Onlays

## Introduction

Technology plays an important role in almost every aspect of life, and dentistry is no exception. Massive advancement in the materials and technologies used in the conservative department has occurred in recent years, revolutionizing the entire dentistry.[1−3]

The time frame that dental restorations are expected to last is dependent on several variables, some of which are material-specific, while others are patient-specific and dentist-specific.[4−6] Moreover, Caries that develop after a restoration has been placed are the most prevalent reasons why a restoration fails, the increased desire for aesthetic restoratives and the mercury toxicity found in amalgam have resulted in a dramatic decrease in the use of amalgam and led the way for a new type of restoration which is the composite resin.[6]

Lately, there has been a substantial movement toward the creation of indirect restorations utilizing a computer-aided design/computer-aided manufacturing (CAD/CAM) system.[7] The CAD/CAM technology has the benefit of lowering the number of manufacturing mistakes. This is accomplished by reducing the amount of time, effort, and labor required by the patient as well as the dentist.[8] Indirect restorations for the posterior teeth can be

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fabricated from a variety of materials, including zirconia, also known as 'ceramic steel,' that are biocompatible, durable, strong, aesthetic, and fatigue-resistant.[9,10]

When a significant percentage of a tooth's tissue has been lost, it is essential to preserve as much of the sound tooth structure as possible while also maintaining the vitality of restored teeth. As a result of this, partial ceramic crowns are quickly becoming more popular in light of the continuing growth in demand for conservative dental treatment.[11–13]

In terms of cuspal coverage, restorations may be categorized as inlays, which cover no cusps, onlays, which cover at least one cusp, or overlays, which cover all cusps. In some situations, simpler designs are desirable.[14,15] Onlays restorations are a useful treatment option for posterior teeth because they not only give superior aesthetics but also reduce tooth tissue loss.[16,17] The geometry of the cavity, including the depth of the preparation, the width of the isthmus, and other factors all influence clinical fracture or failure of ceramic restorations.[18,19]

The forces that may cause fracture of such restorations have been measured using fracture resistance tests, and a preparation design that offers the highest resistance to fracture has been recommended as a result.[20] Vianna et al.[21] concluded that restorations that were made using an indirect procedure using a CAD/CAM system might have been chosen. Even though the isthmus width plays a significant role in the preservation and integrity of the restoration and teeth, many studies and articles discussed the isthmus width in direct restoration .[20–22] So the null hypothesis tested that there would be no significant difference in the fracture resistance of teeth having different preparations designs restored with CAD/CAM ceramic inlays and onlays.[23]

## Patients and methods

### *Materials utilized in the current study*

A listing of the materials and a description of the specifications of each material including the brand name, manufacturer, composition, and application process are presented in Table 1. Table 2 describes the luting resin cement system used in this investigation and its application procedures.

### *Study design*

In this scientific experiment, two factors were applied to assess the fracture resistance of ceramic onlays and inlays created using a CAD/CAM system.

1. Inter-cuspal distance (ICD).
2. Type of restoration (Inlay or Onlay).

### *Specimens' preparation*

To conduct this *in vitro* investigation, 48 extracted human maxillary molars that are free of caries and defects were attained in this study. These teeth were extracted owing to periodontal disease and were collected after patient consent from Mansoura University's College of Dentistry's, Oral and Maxillofacial Surgery clinic. The infection control measures for tooth collection were approved by the Dental College's Ethical Committee. Later, any residual soft tissue and calculus were eliminated using a hand scaler (Zeffiro, Lascod, Florence, Italy). Then a rubber cup with a fine pumice water slurry was used to clean the extracted teeth, and then inspected for signs of disease or damage. During the next three days, a 1 % chloramine-T solution was used to disinfect the teeth.

Only intact, noncarious, and unrestored teeth were included in this study. The teeth were examined under a stereomicroscope (Olympus model SZ-PT, Tokyo, Japan) to ensure the standardization of this study, next, the teeth were kept in distilled water and were periodically changed every 5 days throughout this study and were removed only during the test procedure to avoid any dehydration.

Crown width, height, and length for the chosen teeth characterized by mesio-distal width (9.6 mm–11.3), bucco-lingual dimension (9.02 mm–11.1)

*Table 1. Current research restoration materials.*

| Material | Description | Composition | | Constructor | Batch number | Step by step guideline |
|---|---|---|---|---|---|---|
| IPS e.max ZirCAD | Yttrium-stabilized zirconium oxide | Matrix | Matrix degree | Vivadent, Ivoclar, Amherst, NY | Y43302 | 1. The internal surface of all onlays have been blasted with $Al_2O_3$, 25–70 μm at 1 bar. 2. Then treated with Monobond N for 60 s. 3. Then bonded by G-Cem Capsule |
| | | $ZrO_2$ $Y_2O_3$ $HfO_2$ $AL_2O_3$ | 87–95 wt.% >4.5 % ≤ 7 % ≤5.0 % | | | |

*Table 2. System of luting resin composite used in this investigation.*

| Material | Description | Constructor | Batch number | Steps of application |
|---|---|---|---|---|
| Try-In Paste | Glycerin, mineral fillers and dyes | Schaan, Liechtenstein, Ivoclar Vivadent | 7,405,413 | 1. First the paste was spread on the fitting surface of ceramic restoration. 2. Then, the ceramic was positioned in the correct position |
| Liquid Strip | Glycerin gel | | 740,436 | 1. Spread the coating throughout the whole margin prior to light polymerization. 2. Apply a light cure for 10 s on each part. 3. Then rinse and dry |
| Monobond N | Ethanol, 3-trimethoxysilyl propyl, methacrylate silane, methacrylated phosphoric acid ester, sulphide methacrylate | | Z02CPK | 1. With a brush and a gentle scrubbing motion, apply one layer of the bond. 2. Let 5 s for a gentle air drying.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 | 141,928 | 1. First the capsule was activated. 2. Then mix for 10 s using an amalgamator. 3. Spread cement within the ceramic. 4. Secure the ceramic. 5. Brush excess cement. 6. Light cure each surface for 40 s |

and cervico-occlusal height (8.31 mm (±0.75) that were measured with a digital caliper and no significant variation was observed in any of the measured dimensions between the groups. Then, as a way to stimulate the periodontal ligaments, the roots of the teeth were buried up to 2 mm underneath the CEJ inside a PVC ring that is cylindrically shaped of vinyl chloride (1.4 × 2 cm) manufactured with an auto-polymerizing acrylic resin (Acrostone, Cairo, Egypt). When the acrylic resin had sufficient time to cure, once this time came, each tooth was extracted from the cylinder in which it had been kept.

Polyether impression material was injected into the alveolus of acrylic resin to create the imprint (Soft Impregum by 3 M ESPE, St. Paul, Minnesota). To do this, a scalpel blade was used to cut away the excess polyether substance, creating a space of 0.2 mm–0.3 mm; this is almost equivalent to the conventional thickness of the periodontal ligament.

All of the specimens were placed in deionized water that was kept at 4 °C 24 h before the teeth were prepared. A putty index of each tooth was made before the preparation began so that the dimensions of the preparation and the forms of the restoration could be evaluated.

To prepare the inlay and onlay cavities, a high-speed handpiece (Sirona T3, Ballantyne Corporate Pl Charlotte, USA) using coarse diamond and finishing diamond burs (Inlay Preparation Set 4263; Komet, Lemgo, Germany) and (Onlay prep-set, Intensiv, Viaganello-Lugano, Switzerland) was utilized for the needed preparation. Each bur was changed after four dental preparations to standardize this investigation. The depth of the preparation from the cusp tip to the pulpal floor was only 2.5 mm.

*Restoration procedure*

Group (A) inlays with 75 % cavity width of the ICD (buccal cusp tip-to-palatal cusp tip), (group B) inlays with 100 % width of the ICD, (group C) onlays which had a palatal cusp reduction of 2.0 mm (functional cusp) and 75 % width of ICD, (group D) had a palatal cusp reduction of 2.0 mm (functional cusp) with 100 % width of ICD, (group E) had a palatal cusp reduction of 2.0 mm (functional cusp), a buccal cusp reduction of 1.5 mm (nonfunctional cusp), and a 75 % width of ICD, and group F) had palatal cusp reduction of 2.0 mm (functional cusp), a buccal cusp reduction of 1.5 mm (nonfunctional cusp), and 100 % width of ICD. Each of these groups had a different strategy for the preparation (Fig).

*Digital impression*

An intraoral scanning system (Cerec Omnicam, Dentsply Sirona, Charlotte, NC, USA) was used to scan 48 preparations after specimen processing. Additionally, the CEREC system was used to design and mill 48 yttrium-stabilized zirconium oxide onlays and inlays from IPS e.max ZirCAD blocks.

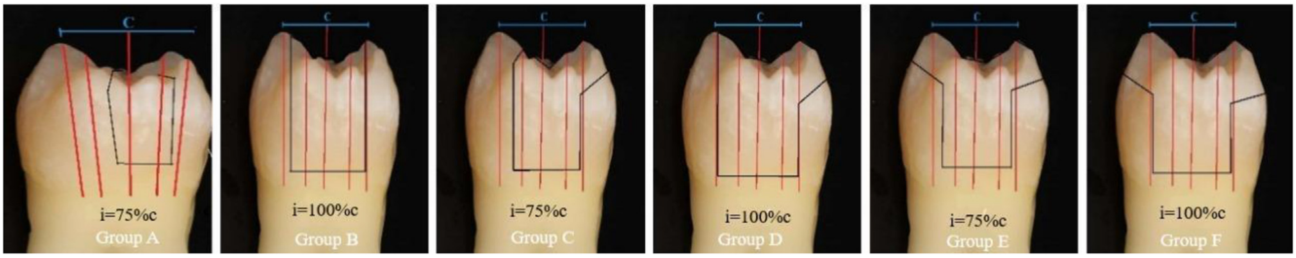


*Fig. Different cavity preparation designs.*

*Fabrication of inlay and onlay restorations*

All restorations were created by the same technician using a consistent process and the manufacturer's guidelines. CAD/CAM approach was used to create all indirect restorations. Intraoral scanning was used to scan the samples before and after processing. The program created indirect restorations based on the Cerec software's Biogeneric Copy feature, restoring the produced samples to their original form.

Indirect restorations were made with an InLab MC XL milling machine from Dentsply Sirona in Bensheim, Germany (IPS e.max ZirCAD). The indirect restorations were fused at 1500 °C, glazed, and burned at 710 °C (Programat EP 5000, Ivoclar Vivadent, Schaan, Lichtenstein). The samples were then put through two stain firing cycles, as directed by the manufacturer. IPS e.max Ceram Glaze paste was used to glaze the pieces (Lot H24056, Ivoclar-Vivadent). The final polish was accomplished on a napless cloth soaked in a diamond suspension with a particle size of 1 m (Hyprez Liquid Diamond type K Standard concentration, Batch 2028, Engis Corporation, Wheeling, IL, USA) while operating a polishing kit (Porcelain Laminate Polishing Kit, Shofu, Ratingen, Germany) at 150 rpm for 5 min. The samples were ultrasonically cleaned in water for 5 min while also being washed with detergent under running water.

*Adhesive bonding of onlays and inlays restorations*

All operations were carried out following the manufacturer's guidelines. To ensure that the restorations have a sufficient marginal fit, the try-in paste was used throughout the restoration process. After that, any remnants of the try-in paste were cleaned out of the cavity. After the try-in procedure, the interior surface of each onlay and inlay was sandblasted to remove any debris. However, to minimize oxygen-hindered layer development, all borders were coated with liquid strips and light polymerized. Finally, finishing and polishing strips were used to smooth out the cement lines (OptraPol, Ivoclar Vivadent).

*Cementation*

When the try-in operations were finished, dual-curing luting resin cement G-CEM CAPSULE (Hasunuma-cho, Itabashi-ku, Tokyo, Japan) was used to bond the inlays and onlays to the teeth. Restorations made with IPS e.maxZirCAD were given a thorough rinsing with water drizzle and then dried out with air. After waiting for 60 s, the fitting surface of each zircon was accustomed by applying a fine layer of coating of priming agent, Monobond N (Vivadent, Ivoclar, Schaan, Liechtenstein). Any remaining excess was dispersed with a strong stream of air. Each specimen went through the same steps to guarantee consistency in this study. G-CEM CAPSULE (Hasunuma-cho, Itabashi-ku, Tokyo, Japan), was applied to the restoration surface, and the restoration was finger-pressed to the pretreatment surface.

An excavator was used to chip away at the excess cement, and then a liquid strip was applied along the restoration margins to avoid the formation of an oxygen inhibition layer during polymerization. Each specimen was light polymerized for 40 s in each direction through a liquid strip.

Flexible discs (Sof-Lex XT Pop On, 3 M ESPE) were used throughout the finishing process of the cement borders so that a smooth surface could be achieved. Following the recommended order of finishing and polishing discs (coarse, medium, fine, and superfine), the cement margins were finished successfully When the restorations were cemented, all of the specimens were kept in distilled water for 24 h at a temperature of 37 °C ± 1 °C.

*Testing*

*Compressive fracture resistance test*

On a universal testing machine (Instron 3345, Canton, MA, USA) that was fitted with a 10-kn load cell, each specimen was loaded in the axial direction with a compressive force, all specimens were loaded until fracture occurred employing a metal sphere with an 8 mm diameter and a crosshead speed of 0.1 mm/min until the metal spherical fractures. The force was applied perpendicularly to the cusp slopes at 0.1 mm/min.

*Statistical analysis*

In terms of the material's resistance to fracture, the data underwent statistical analysis with the Shapiro–Wilk, one-way Analysis of variance, and post hoc-tukey tests. The Shapiro–Wilk test was carried out to ascertain whether or not the force distribution was uniform under the most extreme conditions of compression. The value of $P$ less than 0.05 was chosen to denote a statistically significant correlation.

## Results

Fracture force values were subjected to the Shapiro–Wilk confidence test, which proved that data from all groups were normally distributed ($P > 0.05$). One-way ANOVA followed by a post-hoc Tukey test was used for comparing more than two different groups of parametric data. Thereby, a $P$ value less than 0.05 was considered statistically significant.

One-way ANOVA revealed statistically nonsignificant differences among experimental groups ($P > 0.05$) within force at maximum compressive force (Pascal). Further comparison using a post-hoc test showed a significant difference between group A and group F only ($P = 0.01$). Comparisons between the other groups (1857 ± 511, 2493 ± 801, 2535 ± 971, 2195 ± 354, 2367 ± 543, and 3070 ± 804, respectively) showed insignificant differences, as shown in Table 3.

## Discussion

The degree to which each preparation design could withstand fracturing was the outcome measure that was used. According to the findings of this research, the fracture resistance of the different experimental groups did not vary significantly from one another. As a result, the null hypothesis states that there will not be a substantial difference in the resistance to fracture between various cavity preparation designs with teeth restored with CAD/CAM ceramic onlays and inlays could not be rejected.

Teeth that have been cracked or broken are a frequent clinical concern and are approximately the third leading cause of tooth loss. Massive restorations and severe carious lesions might result in breakage and cusp loss.[24,25] In terms of preparatory design, there is no agreement on how to reduce the cuspal fracture. However, there is a clear relationship between the quantity of missing dental tissue and fracture strength.[25]

This finding is in line with the findings of the investigation of Vianna A.[21] Who found that teeth whose preparation included a larger elimination of dental structure had an impact on their behavior to fracture resistance. Indirect Ceramics restorations are reinforced by the incorporation of oxides, but they still have a high modulus of elasticity and stress concentration inside the restoration's main body.[26–28]

In addition, the results presented here are in agreement with the recommendations made by Stappert and colleagues [26] Who recommended more research regarding the design limitations of inlay cavities. The aforementioned authors analyzed the fracture resistance of inlays, onlays, and natural teeth, and what they found was that there were no significant variations in the average fracture resistance of any of the groups that were put through the

*Table 3. Comparison of force at maximum compressive stress (N) between all groups.*

| | Group A | Group B | Group C | Group D | Group E | Group F | Analysis of variance $P$ value |
|---|---|---|---|---|---|---|---|
| Fracture Resistance Mean ± SD | 1857 ± 511 | 2493 ± 801 | 2535 ± 971 | 2195 ± 354 | 2367 ± 543 | 3070 ± 804 | 0.03* |
| Post-hoc tukey | | $P1 = 0.46$ | $P1 = 0.38$<br>$P2 = 0.99$ | $P1 = 0.92$<br>$P2 = 0.95$<br>$P3 = 0.92$ | $P1 = 0.68$<br>$P2 = 0.99$<br>$P3 = 0.99$<br>$P4 = 0.99$ | $P1 = 0.01$*<br>$P2 = 0.56$<br>$P3 = 0.64$<br>$P4 = 0.14$<br>$P5 = 0.34$ | |

Data expressed as mean ± SD.
SD: standard deviation.
P: Probability *: significance less than 0.05.
Test used: One way Analysis of variance followed by post-hoc tukey.
P1: significance versus group A, P2: significance versus group B, P3: significance versus group C, P4: significance versus group D, P5: significance versus group E.

tests, and because of this, these authors made this suggestion.[29–31]

In addition, the cuspal deflection, and therefore the fracture strength, is affected by the width of the isthmus as well as the depth of the preparation.[16,32] The use of a preparation that is defect-oriented is recommended to preserve dental tissue.[33] Despite this, it was proposed that high-quality clinical investigations be carried out to validate the findings that were discovered in the laboratory.[18]

It is interesting to note that one of the sample groups in this study, group (F), which consisted of onlays that had a palatal cusp reduction of 2.0 mm (functional cusp) and a buccal cusp reduction of 1.5 mm (nonfunctional cusp), demonstrated the best result in terms of fracture resistance, which was different from the results of the other six groups. This discovery reveals a potentially extra advantage that may be gained from the prepared design of ceramic onlays. In addition, according to the logistic extrapolation of the data that was discovered in this research, the preparation of Onlays that have 100 % ICD covering all cusps is related to a lower risk of ceramic fracture.

On the other hand, various cavity preparation designs did not influence the fracture strength of ceramic restorations, the data from the current study does suggest that restorations with and without a difference in cavity design do not differ significantly from one another in terms of their fracture strength. This is a provisional conclusion based on the findings of the study. These results are congruent with those of a prior *in-vitro* experiment that examined the fracture resistance of restored teeth in conjunction with preparation design.[27]

When it is determined that an indirect restoration is the most effective method of care, the clinician is the one who is responsible for deciding the geometric form of the cavity preparation.[34,35] Yet, when applying our findings to clinical settings, care is urged because of the potential for misleading results. It is advised that more research be conducted before particular protocols of preparation designs with a cusp reduction of 100 % may be widely recommended in patients.

The mean fracture strength values of this investigation (1857–3070 N) significantly surpassed maximum axial biting forces in women and males who are biting voluntarily have been documented (480–788 N). The normal range for masticatory forces is 17 N–450 N. and is less than the voluntary maximal axial biting force. Individuals with bruxism often generate forces between 400 and 1100 N involuntarily.[36]

Despite this, in-vitro findings are derived from axial loading, while chewing includes a combination of axial and lateral pressures and movements. Hence, a fracture resistance of more than 1100 N is required to maintain satisfactory clinical performance, which is consistent with the findings of this investigation.[37]

There was found to be some difference in the specimens' levels of fracture strength. It indicates that there are two possible explanations for this phenomenon. Many of the human molars were used and stored in tap water while they were being studied, while others had been withdrawn and stored in tap water for six months before the study, and yet others had been extracted and stored in tap water just days before the study. According to the research, the microhardness of extracted teeth experiences a significant decrease when they are kept in storage for more than two months.[38,39]

In addition, restorations have the potential to fracture as a result of the creation and spread of cracks. This is especially important to keep in mind when dealing with ceramic restorations.[23] The residual tooth structure grows weaker as preparations are made bigger, and occlusal forces produce more cusp deflection than they have ever before. Onlays that incorporate cuspal covering may help prevent cuspal deflection under load, which is why some researchers believe they are the ideal restoration for teeth that have had significant Class II MOD preparations.[40]

Yttria-stabilized Zirconia was employed in the present study. This glass-free, high-strength polycrystalline ceramic material possesses a flexural strength of more than 1000 Mpa and fracture toughness of 9–10 MPa m1/2.[41] This study found that the ceramic had a flexural strength greater than 1000Mpa. In the research conducted by Saridag et al. (2013) [42] It was discovered that the zirconia-based onlays were better able to endure high compressive stresses than the lithium disilicate-based onlays when it came to tooth complex restoration.[43]

The elastic nature of the resin cement that is used in adhesive restorations means that it tends to flex when subjected to stress, which in turn results in a stronger resistance to fracture. As a result, the achievement of success with ceramic inlays depends on making an adhesive-tooth-ceramic interface that isn't compromised in any way.[44]

Laboratory investigation bears its limitation as it is unable to replicate the fundamentals of the oral environment and cannot overcome the difficulties associated with segregating the clinical operative field while working on posterior tooth preparations that are difficult to reach hence, randomized controlled clinical studies with adequate recall intervals are required to confirm laboratory results and provide support for newly developed methods. As the sample size was not calculated at the beginning of the current study, this limitation should also be considered.

*Conclusions*

The use of a CAD/CAM generated IPS e.max Zircad restoration was reliable regardless of the preparation design of the molars that were being restored within the confines of the limitations of this *in vitro* study. In the future, clinical studies on CAD/CAM indirect restorations with a variety of different preparation designs will be required.

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## Data availability

Data is available upon reasonable request from the corresponding author.

## Conflict of interest

The authors of this article confirm that they have no ownership, financial, or other personal interest in the products, services, and/or companies featured in this article.

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