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Evaluation of the Fracture Resistance of Endocrown Restorations Prepared at Different Heights Above the Enamel-Cement Junction

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ABSTRACT

Objective

This study evaluated the fracture resistance of endocrown restorations prepared at different heights above the enamel-cement junction (ECJ). It sought to elucidate the effects of restoration margins on biomechanical behavior and the success of restorations.

Materials and Methods

Eighty extracted mandibular molars were divided into four groups. In Group I, restorations were prepared at the ECJ level; in Group II, 1 mm above; in Group III, 2 mm above and Group IV, 4 mm above the ECJ. Restorations were fabricated from lithium disilicate ceramics using CAD/CAM technology and cemented with appropriate adhesive protocols. The fracture resistance of the restorations was tested using a universal testing machine. Data were assessed for non-normal distribution using the Shapiro-Wilk test, and intergroup comparisons were conducted using the Kruskal-Wallis H test, followed by Dunn's test.

Results

The fracture resistance of Group II (1 mm) and Group III (2 mm) was significantly higher compared to the other groups, with mean values of 1423 ± 75 N and 1389 ± 68 N, respectively ($p < 0.05$). Group I (at the ECJ level) exhibited the lowest fracture resistance, with a mean of 1023 ± 95 N. Group IV (4 mm) demonstrated a mean fracture resistance of 1225 ± 81 N, which was significantly lower than Groups II and III ($p < 0.05$). These findings indicate that positioning the restoration margins closer to the enamel-dentin transition enhances biomechanical stability.

Conclusion

Endocrown restorations prepared 1–2 mm above the ECJ demonstrated superior fracture resistance within the scope of this study. The findings emphasize the significance of preparation height in achieving optimal biomechanical performance. While lithium disilicate ceramics were utilized in this research, the study did not compare different material types. Therefore, further investigations are necessary to evaluate the influence of alternative restorative materials. Additionally, long-term clinical studies are required to validate these findings under intraoral conditions.

Keywords

Endocrown, enamel-cement junction, fracture resistance, CAD/CAM technology, lithium disilicate ceramic, restoration design, biomechanical stability

INTRODUCTION

The restoration of teeth following endodontic treatment is a critical phase aimed at restoring the functional and aesthetic properties of the tooth. However, the loss of hard tissue and structural changes in the tooth during endodontic procedures increase the fracture risk in restored teeth. This highlights the necessity of better understanding the impact of restoration margins, particularly at the ECJ level, on the success of restorations (da Cunha et al., 2015; Zhu, Wang, Rong, Qian, & Wang, 2020).

The ECJ is often used as a reference point in restorations. Various studies have examined the durability, fracture risk, and stress distribution of restorations prepared at different heights above this level. For instance, it has been reported that restorations prepared close to the ECJ exhibit increased stress concentration, leading to a higher fracture risk in these regions (Tribst et al., 2018). Additionally, positioning the restoration margin above this level can enhance biomechanical stability (Otto & Mörmann, 2015).

Endocrown restorations offer a minimally invasive solution, particularly for endodontically treated teeth with significant substance loss. These restorations provide long-term durability through macro-mechanical retention achieved by the axial walls of the pulp chamber and micro-mechanical stability derived from adhesive bonding (Sedrez-Porto, Münchow, Valente, Cenci, & Pereira-Cenci, 2019). The literature demonstrates that endocrown restorations require less tissue removal than traditional crown and post-core restorations, while offering advantages in terms of clinical fit (Biacchi & Basting, 2012).

The type and properties of restorative materials also directly influence the durability of restorations. Using ceramic materials with high fracture resistance and excellent aesthetic properties, such as lithium disilicate, significantly enhances the success of endocrown restorations. However, there is limited information in the literature regarding the effect of different heights above the ECJ on restoration durability (Mannocci et al., 2022; Sedrez-Porto, da Rosa, Da Silva, Münchow, & Pereira-Cenci, 2016; Tribst et al., 2018).

This study aims to evaluate the fracture resistance of endocrown restorations prepared at different heights above the ECJ. The study seeks to better understand restoration margins' impact on biomechanical behavior and clinical success. In this context, the findings are expected to guide clinical practices and restorative materials selection. The null hypothesis of the study states that the preparation height above the ECJ does not affect the fracture resistance of endocrown restorations.

MATERİALS AND METHODS

Ethical Approval and Reporting Guidelines

The study protocol was approved by the Clinical Research Ethics Committee of the university (Reference: B.30.2.ODM.0.20.08/790). This laboratory study was conducted by the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines.

Sample Preparation

Eighty extracted permanent mandibular first and second molars with no caries, fractures, or restorations obtained due to periodontal disease were selected. Teeth with separated roots were cleaned using an ultrasonic scaler to remove debris. The teeth' crown-root lengths, mesiodistal, and buccolingual widths were measured with a digital caliper (CEN-TECH, Virginia, USA) to ensure morphological similarity. After selection, the specimens were stored in thymol solution for the first 24 hours and subsequently preserved in distilled water at room temperature. The sample size was determined using a power analysis based on similar studies in the literature. To achieve an alpha level of 0.05 and a statistical power of 0.80, a minimum of 15 specimens per group was calculated as necessary. To account for potential specimen loss during experimental procedures, 20 specimens were allocated to each group, resulting in a total of 80 teeth.

Root Canal Treatment and Cavity Preparation

Root Canal Treatment

Endodontic access cavities were prepared using a diamond fissure bur and removed pulp tissue. Working lengths were determined using a #15 K-type file (Dentsply Maillefer, Ballaigues, Switzerland). Root canals were shaped using rotary nickel-titanium files (ProTaper Next, Dentsply Maillefer) with the crown-down technique, finishing with an X2 (#25.06) file for mesial root canals and an X3 (#30.07) file for distal root canals. . During preparation, the root canals were irrigated with 2.5% sodium hypochlorite (NaOCl) after each file to disinfect the canal and dissolve organic tissue. A final rinse was performed using 17% EDTA to remove the smear layer, followed by distilled water to neutralize residual irrigants. The root canals were dried with paper points (Diadent; Diadent Group International; Chongchong Buk Do, South Korea). After drying the root canals with paper points, the root canals were obturated with appropriate gutta-percha cones (Dentsply Maillefer and Diadent #25.02, Diadent Group International, South Korea) using AH Plus (Dentsply, De Trey Konstanz, Germany) as the sealer and the lateral compaction technique. Excess gutta-percha was removed using a heated instrument.

Cavity Preparation

Cavity preparation was performed using blunt-tipped tapered diamond burs (Piranha Diamond, SS White, NJ, USA) to achieve a minimum coronal wall thickness of 2 mm and a taper angle of 8°–10° toward the occlusal plane. The cavity wall thickness was standardized using a periodontal probe and a digital caliper, and sharp edges and corners were rounded. After preparation, the cavities were sealed with Cavit G (3M Espe, Seefeld, Germany) and stored in distilled water.

Grouping of Samples

The samples were divided into four groups based on the ECJ level and a control group. The grouping was performed by making cuts at the ECJ level and 1 mm, 2 mm, and 4 mm above it using a water-cooled, low-speed linear precision saw (Isomet 5000, Buehler, Illinois, USA).

- **Group I:** Cavity preparation at the ECJ level.
- **Group II:** Cavity preparation 1 mm coronally above the ECJ level.
- **Group III:** Cavity preparation 2 mm coronally above the ECJ level.
- **Group IV:** Cavity preparation 4 mm coronally above the ECJ level.

After removing the temporary filling in each group, the pulp chamber was treated with alcohol. The height of the pulp chamber was standardized using a periodontal probe. For specimens with pulp chamber heights exceeding 2 mm, canal orifices were sealed with flowable composite resin (3M Filtek Ultimate, 3M ESPE, St. Paul, USA). The pulp chamber floor was flattened to a depth of 2 mm using a diamond fissure bur, and the final shaping of the walls was completed with coarse and fine diamond burs. A minimum wall thickness of 2 mm was maintained throughout the preparation.

Preparation of Restorations Using the CAD/CAM System

Digital Impression and Molding

Digital impressions of all specimens were taken using the Cerec Omnicam (Sirona Dental Systems, Bensheim, Germany). To preserve the contours of each tooth, the teeth were covered with a silicone impression material (Optosil, Heraeus Kulzer, Germany), extending 2 mm below the ECJ.

Restoration Design and Milling

The restoration design process was done using CEREC Software 4.4.4 (Sirona Dental Systems) on a CEREC AC computer screen. Milling was performed using the CEREC MC XL milling unit (Sirona Dental Systems).

Standardization and Milling Parameters

The ECJ level was standardized based on the crown length of mandibular first molars and second molars and the minimum required porcelain thickness for the occlusal surface. Measurements were determined as 5.5 mm from the cervical band to the central fossa and 6.5 mm to the highest cusp tip. These dimensions were aligned parallel to the long axis of the tooth. The milling time for each restoration block was approximately 12 minutes, and the process was applied uniformly to all 80 specimens.

Cementatlon of Restorations

Enamel Surface Preparation

1. **Etching:** The enamel surface of each tooth was etched with 37% phosphoric acid for 30 seconds, rinsed with water for 20 seconds, and dried with air.

2. **Adhesive Application:** A bonding agent (Scotchbond Universal Adhesive, 3M ESPE, St. Paul, MN, USA) was brushed onto the surface for 20 seconds, the excess was removed with air, and the surface was light-cured for 10 seconds.

Restorative Surface Preparation

1. **Etching:** The restoration surfaces were etched with 9.5% hydrofluoric acid for 40 seconds, rinsed with water, and dried with air.

2. **Silane Application:** A silane agent (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the surface, allowed to sit for 60 seconds, and then dried with air.

Cementation Procedure

1. **Cement Application:** Maxcem Elite dual-cure resin cement (Kerr Corporation, Orange, CA, USA) was applied to the bonding surface of the tooth and the restoration area.

2. **Placement and Initial Polymerization:** The restoration was placed in the cavity and polymerized with finger pressure. Excess cement was removed after 3 seconds.

3. **Final Polymerization:** All surfaces of the restoration were light-cured for 40 seconds.

Aging Process

Simulation Setup:

The specimens were placed in a dual-axis chewing simulator with six experimental chambers (MOD Dental; Esetron, Ankara, Turkey). This computer-controlled system features dual motors for horizontal and vertical movements, ensuring coordinated thermal cycling and mechanical motions.

Thermal Cycling and Mechanical Loading

- **Thermal Cycling:** The specimens underwent 5000 cycles of thermal changes between 5°C and 55°C, each cycle lasting 60 seconds.

- **Mechanical Loading:** Chewing forces of 50 N were applied using stainless steel balls with a 5 mm diameter. Each specimen was subjected to 250,000 vertical movements over a 2 mm distance at a speed of 50 mm/s. The simulation parameters were chosen based on the methods of Krejci et al. to represent one year of chewing forces.

The thermal cycling protocol involved 5000 cycles between 5°C and 55°C, simulating approximately one year of intraoral conditions based on previous studies (Tribst et al., 2018). This parameter was chosen to replicate the thermal stress experienced in the oral cavity due to daily temperature variations.

The mechanical loading protocol applied a 50 N chewing force, representing the average masticatory force exerted on posterior teeth. This value was selected to simulate clinical conditions while minimizing excessive force that could lead to unrealistic failure modes, as supported by findings in Biacchi & Basting (2012) and other biomechanical studies.

Post-Simulation Storage

Following the simulation, the specimens were stored in distilled water at room temperature until fracture testing.

Fracture Resistance Testing

Test Procedure

The fracture resistance of each specimen was evaluated using a universal testing machine (Instron; Instron Corp, MA, USA). Specimens were positioned parallel to the ground in the device, and a stainless steel indenter with a 5 mm diameter was placed at the center of the occlusal surface of the restoration. A vertical force was applied perpendicular to the occlusal plane at a 1 mm/min crosshead speed until fracture occurred.

Data Recording and Classification

The maximum force at the fracture point was recorded in Newtons (N). Specimens not fracturing under the devices maximum capacity of 2000 N were classified as "No Fracture."
In this study, some specimens did not break under the maximum force of 2000 N and were evaluated as "No Fracture."

Fracture Type Analysis

Stereomicroscopic Examination

After fracture testing, each specimen was analyzed using a stereomicroscope (Leica EZ4 D, Leica Microsystems, Wetzlar, Germany). Detailed photographs of the tooth surfaces were taken, and fracture characteristics were closely examined. Fractures were categorized based on their location and nature into restorable (above the ECJ) and non-restorable (below the ECJ). These categorizations were used to evaluate the potential for clinical repair, with the majority of fractures being classified as restorable in this study

Statistical Analysis

The data were analyzed using IBM SPSS V23 (Chicago, IL, USA). The normality of data distribution was assessed with the Shapiro-Wilk test. For non-normally distributed data, fracture resistance comparisons among groups were performed using the Kruskal-Wallis H test. Pairwise comparisons between groups were conducted using the Dunn test. Numerical data were presented as mean ± standard deviation, while categorical data were expressed as frequency (percentage). Results with a p-value < 0.05 were considered statistically significant.

RESULTS

1. Fracture Resistance Values of the Groups

The fracture resistance values of the groups revealed that Group II exhibited the highest fracture resistance compared to the other groups. Statistical analyses confirmed significant differences among the groups ($p < 0.05$). The fracture resistance values of the groups are summarized as follows and presented in Table 1:

Table 1: *Fracture Resistance Values of the Groups (Newtons)*

Group	Mean ± Standard Deviation (N)	Median (N)
Group I	1023 ± 95	1010
Group II	1423 ± 75	1430
Group III	1389 ± 68	1390
Group IV	1225 ± 81	1230

These results demonstrate that restorations in Group II (1 mm above the ECJ) and Group III (2 mm above the ECJ) outperformed the others in terms of fracture resistance. In contrast, Group I (at the ECJ level) exhibited the lowest fracture resistance. The findings suggest that preparing the restoration margin 1–2 mm above the ECJ is critical to restoration success.

2. Normality Test

The Shapiro-Wilk test results indicated that none of the groups followed a not normal distribution ($p < 0.05$). Consequently, non-parametric analysis methods were employed.

3. Intergroup Difference Analysis

The Kruskal-Wallis H test revealed a statistically significant difference among the groups ($p = 0.027$). This finding indicates that fracture resistance varied significantly between the groups. The analysis results are presented in Table 2:

Table 2: *Kruskal-Wallis H Test Results*

Test Statistic	p-value
9.16	0.027

4. Pairwise Comparisons

Dunn's test was performed to further explore the significant differences among the groups. After applying the Bonferroni correction, a statistically significant difference was found between Group I and Group II ($p = 0.0394$). No significant differences were observed between the other group pairs. The pairwise comparison results are summarized in Table 3:

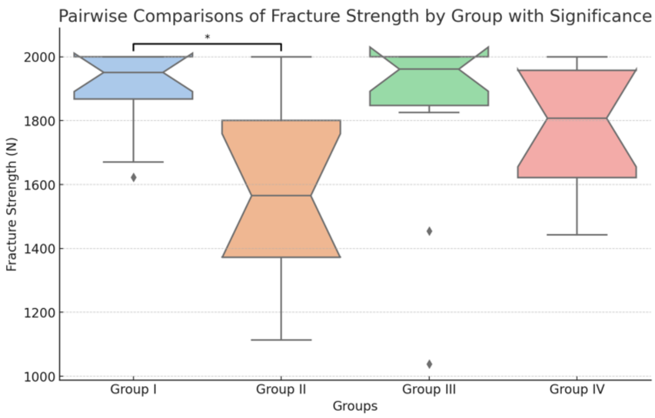
Table 3: *Pairwise Comparison Results*

Group 1	Group 2	U Statistic	p-value	Bonferroni Corrected p-value
Group I	Group II	119.0	0.0066	0.0394
Group I	Group III	77.0	0.7895	1.0000
Group I	Group IV	100.5	0.1033	0.6198
Group II	Group III	37.0	0.0447	0.2684
Group II	Group IV	47.0	0.1569	0.9411
Group III	Group IV	93.5	0.2232	1.0000

5. Visualization and Distribution Analysis

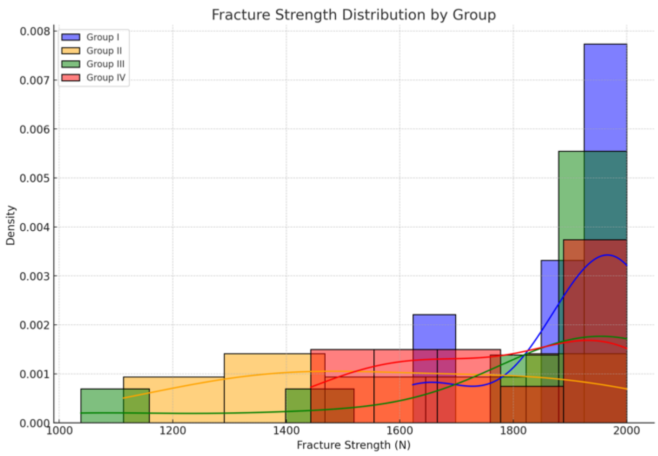
The distribution of fracture resistance among groups was visualized using both box plots and histogram density plots (Figures 1 and 2). These visualizations provide a clearer understanding of the differences and distribution characteristics across the groups.

Fig 1: Distribution of Fracture Resistance by Group (Box Plot)
A significant difference was observed between Group I and Group II ($p < 0.05$).



The fracture resistance values of the groups are visualized, with the significant difference between Group I and Group II indicated by an asterisk (*).

Fig 2: Distribution of Fracture Resistance Among Groups (Density Plot)
The fracture resistance values of the groups are presented using histogram and kernel density plots to illustrate the distribution characteristics.



- The fracture resistance values of each group are illustrated using histograms and density functions.

- These plots are used to understand better the similarities and differences in the distributions of the groups

Interpretation of Results

This study evaluated the fracture resistance of endocrown restorations prepared at different heights above the ECJ. The findings demonstrate that Group II exhibited higher fracture resistance than the other groups, underscoring the critical role of the ECJ level in restoration success.

Superior Fracture Resistance in Group II:

The higher fracture resistance observed in Group II reflects the biomechanical advantages of positioning the restoration margin near the EDJ. This region allows the restoration to benefit from the structural support of both dentin and enamel, optimizing stress distribution. A systematic review by Sedrez-Porto et al. (2016) also identified the proximity of the restoration margin to the EDJ as a favorable factor for fracture resistance.

Difference Between Group I and Group II:

The statistically significant difference between Group I and Group II ($p < 0.05$) indicates that restorations with margins near the ECJ level exhibit reduced fracture resistance. Similarly, Zhu et al. (2020) reported that stress concentration increases when the restoration margin is positioned at the ECJ, leading to a higher fracture risk.

Comparison Between Group III and Group IV:

The lack of significant difference between Group III and Group IV suggests that maintaining the restoration margin within a dentin-supported region ensures consistent fracture resistance. This finding aligns with the biomechanical analysis conducted by Tribst et al. (2018).

Role of Heights Above the ECJ:

Restorations prepared 1–2 mm above the ECJ exhibited more balanced stress distribution and higher fracture resistance, supporting the study hypothesis. This outcome is consistent with the findings of Biacchi and Basting (2012), who highlighted that endocrowns are less invasive and more durable than post-core restorations.

DISCUSSION

This study evaluated the fracture resistance of endocrown restorations prepared at different heights above the ECJ. The findings revealed that restorations prepared 1–2 mm above the ECJ exhibited significantly higher fracture resistance than other groups. This underscores the critical role of the ECJ level in determining the success of restorations and its biomechanical behavior. A statistically significant difference was observed only between Group I and Group II, while no significant differences were found between the other group comparisons.

Restoration margins at the ECJ level can directly influence the supportive effects of dentin and enamel tissues. Specifically, restorations prepared closer to the enamel-dentin junction in this study demonstrated improved stress distribution and increased fracture resistance. Similarly, Zhu et al. (2020) reported that restorations nearer to the enamel-dentin junction reduce stress concentration, enhancing restoration success (Zhu et al., 2020).

The mechanical properties of the material used in restorations above the ECJ likely influenced the observed fracture resistance. In this study, lithium disilicate-based ceramics fabricated using CAD/CAM technology were used, known in the literature for their high bonding strength and mechanical durability (Sedrez-Porto et al., 2016). However, although leucite-reinforced glass ceramics provide bonding strength comparable to dentin, they exhibit lower mechanical durability than lithium-disilicate ceramics (Govare & Contrepois, 2020).

The impact of proximal wall defects on restoration success remains a debated topic in the literature. Although this study did not specifically examine proximal defects, restorations prepared above the ECJ demonstrated high mechanical strength, suggesting that preparation height plays a critical role in maintaining restoration stability. Further studies are needed to evaluate the influence of proximal defect size on fracture resistance. Tribst et al. (2018) emphasized that understanding stress distribution in restorations under load is crucial for comprehending crack initiation and propagation mechanisms (Huang, Fokkinga, Zhang, Creugers, & Jiang, 2023; Tribst et al., 2018).

Endocrown restorations result in less tooth structure loss compared to traditional post-core restorations. This characteristic not only enhances the long-term durability of the tooth but also reduces potential complications during the restoration process. Biacchi and Basting (2012) highlighted that endocrown restorations are less invasive and offer comparable or even higher fracture resistance than post-core restorations (Biacchi & Basting, 2012).

Lithium disilicate ceramics produced using CAD/CAM technology offer superior mechanical durability and exceptional aesthetics. These ceramics are ideal materials for endocrown restorations due to their resistance to microcracks and strong bonding properties (Sedrez-Porto et al., 2016). However, alternative materials such as leucite-reinforced glass ceramics offer comparable aesthetic performance but are less effective than lithium disilicate in terms of mechanical durability (Huang et al., 2023).

Integrating CAD/CAM technology into endocrown restorations optimizes clinical workflows and enhances patient comfort. Completing restorations in a single session facilitates patient compliance and improves clinical efficiency (Uzun, Timur, & Şenel, 2024). Endocrown restorations enhance stability by combining macro-mechanical and micro-mechanical retention principles. By leveraging support from the pulp chamber, they improve resistance to masticatory forces. Vianna et al. (2018) emphasized that dentin-supported restorations provide more balanced stress distribution, thereby reducing the risk of fracture (Vianna et al., 2018). Endocrowns are particularly suitable for the restoration of posterior teeth. In regions subjected to high masticatory forces, endocrown restorations effectively meet functional and aesthetic expectations.

This study provides valuable insights into the fracture resistance of endocrown restorations prepared at different heights above the ECJ. However, it is important to acknowledge certain limitations. First, the study was conducted under laboratory conditions, and long-term clinical follow-up was not included, which could provide additional insights into the restorations' performance under intraoral conditions. Second, the influence of proximal wall defects was not evaluated, although such defects could impact the mechanical behavior of restorations. Future studies incorporating these variables are necessary to validate and expand upon the findings presented here.

The findings of this study demonstrate that preparing endocrown restorations at a height of 1–2 mm above the ECJ enhances restoration success. Based on these results, clinical recommendations can be summarized as follows:

1. Enamel-Cement Junction (ECJ) Guidance

- **1–2 mm Above is Preferred:**
  The results indicate that positioning the restoration margin 1–2 mm above the ECJ offers advantages in terms of fracture resistance. A systematic review by Sedrez-Porto et al. (2016) highlighted that restorations placed near the enamel-dentin junction optimize stress distribution and improve fracture resistance (Sedrez-Porto et al., 2016).

- **Avoid Restorations Near the Enamel-Cement Junction (ECJ):**
  Zhu et al. (2020) reported that restoration margins close to the ECJ generate high stress concentrations, leading to restoration failure (Zhu et al., 2020).

2. Selection of Restoration Material

- **Lithium Disilicate Ceramics are Recommended:**

  Lithium disilicate-based ceramics offer superior mechanical durability and aesthetic performance. This material provides an ideal restorative solution when combined with CAD/CAM technology. Aggarwal et al. (2012) reported that lithium disilicate ceramics are more durable than post-core restorations and represent a minimally invasive option (Aggarwal, Singla, Miglani, & Kohli, 2012).

- **Careful Selection of Alternative Materials:**
  Alternative materials like leucite-reinforced glass ceramics may be considered in cases with lower mechanical durability requirements. However, stronger materials like lithium disilicate are recommended for regions subjected to higher stress.

3. Preparation and Bonding Procedures

- **Preparation Design:**
  In endocrown restorations, the preparation is recommended to effectively utilize the pulp chamber. This approach enhances both macro-mechanical and micro-mechanical retention. Tribst et al. (2018) noted that restorations supported by the pulp chamber provide a more balanced stress distribution (Tribst et al., 2018).

- **Bonding Protocols:**
  Effective use of phosphoric acid etching, silane application, and adhesive systems is essential to ensure strong adhesion. Sedrez-Porto et al. emphasized the critical role of appropriate bonding protocols in the success of restorations (Sedrez-Porto et al., 2019).

4. Practical Approaches in Clinical Applications

- **Single-Session Restoration:**
  With CAD/CAM technology, endocrown restorations can be fabricated and applied in a single session. This enhances patient comfort and accelerates clinical workflows (Dejak & Młotkowski, 2013).

- **Endocrowns for Posterior Teeth:**
  Endocrown restorations are an ideal solution for posterior teeth, where high masticatory forces are present, as they effectively meet functional and aesthetic requirements (Inchingolo et al., 2016).

5. Monitoring and Maintenance

- **Periodic Check-Ups:**
  Regular clinical follow-ups are recommended to enhance the success of endocrown restorations. These check-ups enable early detection of potential cracks or failures. Otto and Mörmann (2015) emphasized that routine monitoring and patient education are critical for the long-term success of endocrown restorations (Otto & Mörmann, 2015).

- **Patient Education:**
  Patients should be informed about the importance of maintaining proper oral hygiene and adopting preventive care measures to ensure the longevity of their restorations.

CONCLUSION

This study evaluated the effect of different heights above the ECJ on the fracture resistance of endocrown restorations. The findings demonstrated that positioning the restoration margin 1–2 mm above the ECJ significantly improves restoration success. Additionally, using ceramic materials with strong mechanical properties, such as lithium disilicate, dramatically enhances the durability of restorations. These results provide clinical guidance in restoration design and material selection. Future studies evaluating different restorative materials and long-term clinical applications will further contribute to understanding the effectiveness of endocrown restorations.

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