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Effect of internal taper of endocrown preparation on the adaptation of 3D-printed restorations

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Abstract

Objective: This study aimed to evaluate the influence of different internal taper angles in endocrown preparations on the marginal and internal adaptation of 3D-printed restorations.

Methods: Three standardized mandibular first molar models were prepared with internal taper angles of 6°, 10°, and 22°. Each model was scanned 12 times, and endocrown restorations were digitally designed and fabricated with a 3D printer using Freeprint® Temp resin. All restorations were seated by a single operator, and the adjustment time and frequency were recorded. Adaptation was assessed using the replica technique, and marginal, axial, pulpal, and axio-pulpal line angle gaps were measured under a stereomicroscope. Data were analyzed using one-way ANOVA and Tukey's post-hoc test at the significance level of $P<0.05$.

Results: The pulpal gap was significantly larger in the 22° taper group compared to both the 6° ($P<0.001$) and 10° ($P=0.001$) groups. The 6° taper group exhibited significantly greater marginal misfit than the 10° ($P=0.035$) and 22° ($P=0.021$) groups. The axio-pulpal line angle misfit was significantly higher in the 22° taper group than in the 6° group ($P=0.016$). No significant difference was observed in axial misfit among the groups ($P=0.169$). Notably, the 22° taper group required significantly less adjustment time and fewer adjustment attempts than the other groups ($P<0.05$).

Conclusions: All three taper angles yielded restorations with clinically acceptable adaptation. Increasing the internal taper from 6° to 22° improved marginal fit and reduced clinical chairside adjustments; however, it resulted in a deterioration of pulpal adaptation.

Keywords: Dental marginal adaptation, Dental preparation, Dental prosthesis, Permanent dental restoration, Temporary dental restoration, Three-dimensional printing

Introduction

The techniques and materials employed in the coronal reconstruction of endodontically treated teeth play a critical role in the long-term success of the treatment (1). The most commonly used approach is the fabrication of a post and core followed by the placement of a full-coverage crown (2–6). However, in cases with sufficient residual tooth structure, reliance on macro-mechanical retention is no longer a necessity. With the advancements in adhesive dentistry, the traditional use of posts and cores has declined, and minimally invasive alternatives such as endocrowns have gained popularity (7–9).

As with all indirect restorations, the marginal and internal adaptations of endocrowns significantly influence their clinical performance and longevity (8, 9). Poor marginal adaptation may lead to plaque accumulation, secondary caries, and cement dissolution. Similarly, excessive internal gaps can concentrate stress on the luting cement and the restoration interface, increasing the risk of debonding or fracture (10).

A review of the literature indicates that several factors affect the marginal adaptation of endocrowns. These include the type of restorative material, finish line configuration, pulp chamber depth, degree of axial wall taper, internal angle sharpness, pulpal floor morphology, and type of luting agent. Based on current evidence, optimal preparation guidelines include a minimum pulp chamber depth of 3 mm, occlusal reduction of 2–3 mm, a 90-degree circumferential butt-joint finish line, rounded internal angles, a flat pulpal floor, and well-sealed canal orifices (11–16).

To enhance the seating and internal adaptation of endocrowns, the internal walls of the preparation are typically designed with a slight divergence to eliminate

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undercuts and facilitate insertion (17). However, increasing the taper beyond an optimal range can compromise the mechanical retention of the restoration, potentially affecting its long-term stability (18). Therefore, selecting an appropriate axial taper is crucial for achieving a balance between optimal fit and adequate retention, both of which are essential for the clinical success and longevity of endocrowns.

Previous studies have demonstrated that axial taper significantly influences the internal fit of restorations (19, 20). For instance, Darwish et al (20) observed that a 6-degree taper produced smaller internal gaps compared to a 10-degree taper. In contrast, other studies have suggested that increasing the taper can reduce seating friction, thereby facilitating easier insertion and potentially improving internal adaptation (19, 21). These contrasting findings underscore the complexity of the relationship between taper and fit and highlight the need for further research to determine the optimal taper angle that balances adaptation and retention.

Three-dimensional (3D) printing, first introduced in 1986, has changed restorative dentistry by enabling the rapid, accurate, and cost-efficient fabrication of dental restorations. Compared to traditional subtractive milling, 3D-printed restorations have demonstrated promising results in terms of marginal and internal adaptation (22–25). While much attention has been given to material properties and printing accuracy (24, 25), there remains a gap in knowledge regarding how preparation geometry, such as axial wall taper, affects the fit of such restorations. Therefore, this study aimed to assess the effect of varying axial taper angles (6°, 10°, and 22°) on the marginal and internal adaptation of 3D-printed endocrown restorations. The null hypothesis of the study was that varying the taper angle would have no significant effect on the marginal and internal adaptation of 3D-printed endocrown restorations.

Materials and Methods

The study protocol was approved by the ethics committee of the Tehran University of Medical Sciences under the code IR.TUMS.DENTISTRY.REC.1398.065.

Sample size calculation

Based on the findings of Shin et al. (9), the required sample size was calculated using G*Power software (Heinrich-Heine-Universität, Düsseldorf, Germany). A total of 12 specimens per group was determined to be adequate to detect statistically significant differences between groups, assuming a significance level (α) of 0.05 and a statistical power ($1-\beta$) of 0.90.

Endocrown preparation

Initially, three acrylic models of mandibular first molars were scanned using the Cerec Omnicam scanner (Dentsply Sirona Inc., Charlotte, NC, USA). Then, occlusal surfaces were uniformly reduced by 2 mm using a diamond bur (#806 314 199 534, Ø18, Jota). The butt-joint margins were finished with the same bur at low speed. Internal cavities were prepared with a standardized depth of 5 mm from the margin, incorporating three different axial wall tapers (6°, 10°, and 22°) between the opposing internal walls. A flat-end diamond bur (#806 314 110 534, Ø18, Jota) was used for this purpose. Undercuts were eliminated, internal line angles were rounded, and the path of insertion was verified. Axial wall preparations were performed using a milling machine equipped with a parallelometer (Impla 3D Theta System, Schutz Dental GmbH, Rosbach, Germany) to ensure accuracy and reproducibility. Final preparations were scanned, and taper angles were confirmed using Ansys Workbench 19.2 software (Ansys® Inc., Houston, TX, USA).

Design and fabrication of restorations

Each prepared tooth model was scanned 12 times using a calibrated Cerec Omnicam scanner, corresponding to the required sample size of 12 endocrowns per taper group. Cerec 4.5.4 software was used to design the endocrowns, with a cement space of 30 µm incorporated (15). Digital design files were then transferred to a 3D printer (Digi Dent 3D Printer, Iran), and endocrowns were fabricated using Freeprint® Temp resin (DETAX GmbH & Co. KG, Ettlingen, Germany) with a 50 µm layer thickness. The printer utilized a 405 nm UV LED projector, with a resolution of 1280×800 pixels, printing dimensions of 90×56×130 mm, product size of 450×410×900 mm, XY resolution of 25–100 µm, and Z resolution of 1 µm.

Misfit evaluation

Endocrowns were seated on their corresponding models by a trained operator, and the required adjustment time and frequency were recorded. The marginal and internal fit was assessed using the replica technique, evaluating the misfit at marginal, axial, pulpal, and axio-pulpal line-angle areas.

Each tooth model was securely mounted in medium-body putty silicone (blue) (Betasil® Vario Putty Soft, Müller-Omicron GmbH & Co. KG, Lindlar, Germany) to ensure stability during the evaluation (Figure 1A). To prevent adhesion, the internal surface of each endocrown was lightly moistened before seating. Low-viscosity (light-body) addition silicone (pink) (Betasil® Vario Light; Müller-Omicron GmbH & Co.) was injected into the prepared cavity, and the corresponding endocrown was seated using finger pressure and maintained for 2 minutes (Figure 1B).

After polymerization, the endocrown was gently removed, and an additional layer of high-viscosity putty silicone (blue) was applied over the light-body material to simulate the endocrown (Figure 1C).

Once the putty layer had fully set, the tooth model was removed (Figure 1D) and replaced with medium-body silicone (green) (Denu Medium Body Fast Set, HDI Inc., Seongnam-si, Gyeonggi-do, Republic of Korea) with a different color to enhance color contrast during measurement (Figure 1E).

For each endocrown, two silicone replicas were produced. One was sectioned mesiodistally and the other buccolingually, using a surgical scalpel to facilitate internal evaluation (Figure 1F). In each section, the thickness of the light-body silicone layer (pink; representing the gap space) was measured at 16 standardized locations: two at the marginal edge, two at the axio-pulpal line angles, eight along the axial walls (two per wall), and four on the pulpal floor.

Measurements were obtained using a Leica stereomicroscope (Leica Microsystems, Wetzlar, Germany) fitted with a Dino-Lite 5MP Edge AM7115MZT digital camera (AnMo Electronics Inc., New Taipei City, Taiwan) at 50× magnification. The mean light-body material thickness values for each region were

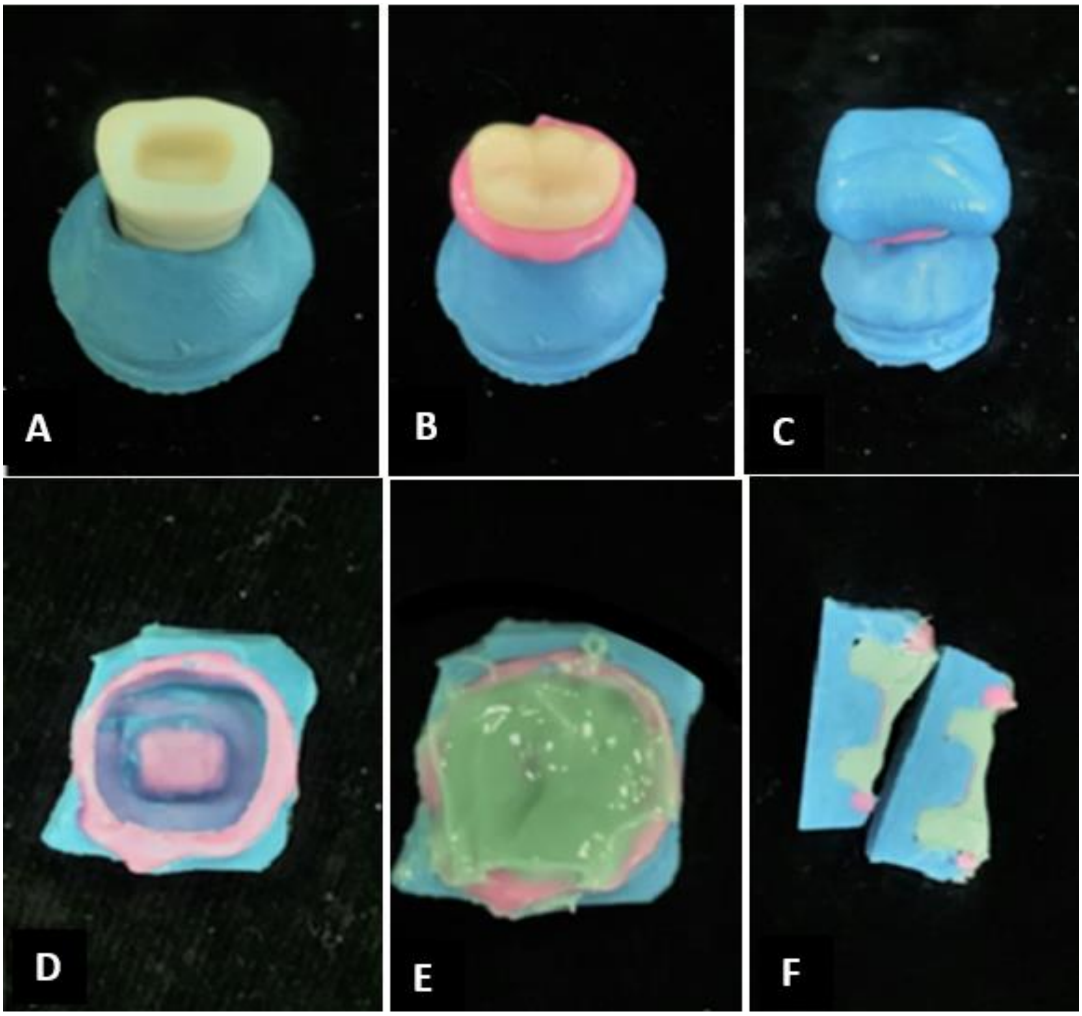

Figure 1. Replica technique for misfit evaluation: A) Tooth model mounted in putty addition silicone, B) Low-viscosity addition silicone (pink) was injected into the prepared cavity, followed by seating of endocrown, C) Endocrown was removed and high-viscosity putty silicone layer (blue) was applied to replace the endocrown, D) Tooth model was removed, E) Medium-body silicone (green) was injected to fill the tooth model space, F) Two silicone replicas were sectioned, one mesiodistally and the other buccolingually

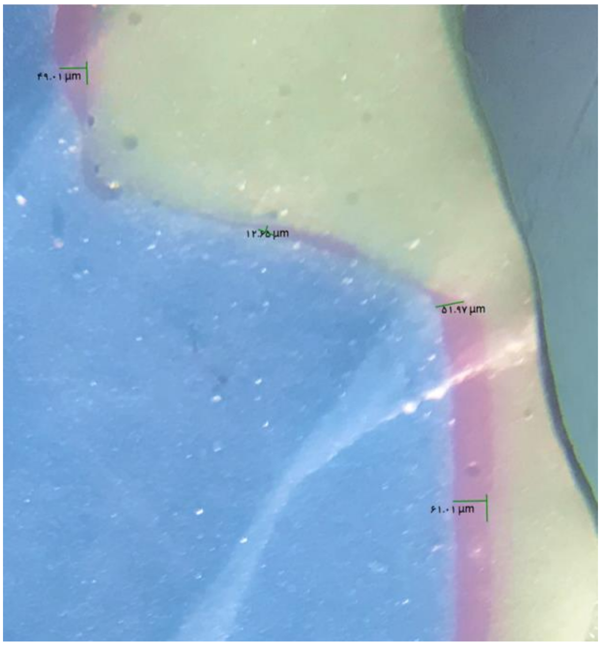

Figure 2. Measuring the misfit at different areas under a stereomicroscope

calculated and recorded as the corresponding misfit (Figure 2) (19, 26).

Statistical analysis

Data were analyzed using SPSS (version 25; IBM Corp., Armonk, NY, USA). The normality of the data was confirmed by the Shapiro-Wilk test (P>0.05). One-way ANOVA was used to assess differences between groups, followed by Tukey's post hoc test for pairwise comparisons. The level of significance was set at α = 0.05.

Results

The comparison of misfits across different taper groups is presented in Table 1. One-way ANOVA revealed statistically significant differences among the three taper groups in the pulpal floor (P<0.001), marginal area (P=0.013), and axio-pulpal line angle (P=0.016) regions. However, no significant between-group difference was observed in the axial wall (P=0.169).

Pairwise comparisons using Tukey's post hoc test showed that the pulpal floor misfit in the 22-degree taper group was significantly higher than that observed in the 6-degree (P<0.001) and 10-degree (P=0.001) groups. In contrast, the marginal misfit was significantly greater in the 6-degree taper group compared to both the 10-degree (P=0.035) and 22-degree (P=0.021) groups. Additionally, the axio-pulpal line angle misfit in the 22-degree taper group was significantly higher than that of the 6-degree group (P=0.016). No other significant differences were found among the groups (P>0.05; Table 1).

Regarding the adjustment process, one-way ANOVA demonstrated a significant difference in both the frequency (P<0.001) and duration (P<0.001) of adjustments among the taper groups (Table 2). Tukey's post hoc analysis revealed that the frequency of adjustments significantly decreased as the taper increased, with statistically significant differences noted between the 6- and 10-degree groups (P=0.034), the 6- and 22-degree groups (P<0.001), and the 10- and 22-degree groups (P<0.001). Furthermore, the mean adjustment time was significantly shorter in the 22-degree group than in the 6-degree and 10-degree taper groups (P<0.001 for both). No significant difference was observed in adjustment time between the 6- and 10-degree groups (P=0.14; Table 2).

Discussion

This study evaluated the influence of axial wall taper (6, 10, and 22 degrees) on the adaptation of 3D-printed endocrowns. The findings revealed significant differences in pulpal, marginal, and axio-pulpal line-angle misfit among the taper groups, whereas no significant difference was observed in axial misfit. Consequently, the null hypothesis was rejected.

Table 1. Mean and standard deviation (SD) of misfit values (in micrometers) among different taper groups at four measurement areas: pulpal floor, axial wall, marginal area, and axio-pulpal line angle

Groups	Pulpal floor	Axial wall	Marginal area	Axio-pulpal line angle
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
6° taper	64.34 ± 10.20 [a]	29.66 ± 8.31	61.44 ± 9.27 [a]	57.52 ± 10.019 [a]
10° taper	67.85 ± 6.52 [a]	32.18 ± 11.27	50.08 ± 10.23 [b]	60.81 ± 9.90 [ab]
22° taper	83.17 ± 10.93 [b]	25.45 ± 5.02	49.12 ± 12.25 [b]	70.83 ± 13.01 [b]
P value	< 0.001*	0.169	0.013*	0.016*

Different superscript letters indicate significant differences between groups at P<0.05.

The mean misfit across the assessed regions including marginal area, axial wall, pulpal floor, and axio-pulpal line angle—ranged from 25.45 ± 5.02 µm in the axial wall of the 22-degree taper group to 83.17 ± 10.93 µm in the pulpal floor of the same group. These values fall within the clinically acceptable range of 75–160 µm for marginal and internal misfit, as suggested in the literature (27-29).

Among the measured regions in this study, the pulpal floor consistently exhibited the highest misfit across all taper groups. This result aligns with the findings of Hajimahmoudi et al. (19), who similarly reported greater discrepancies at the pulpal floor in digitally fabricated restorations. One plausible explanation is the limited field depth of intraoral or laboratory scanners, which may affect the accurate capture of deeper regions (e.g., pulpal floor) within the cavity preparation (19,30). This deficit happens due to the restricted light reflection and shadowing effects in narrow, deep spaces, reducing the accuracy of the digital impression and ultimately affecting the internal adaptation of the restoration at the pulpal floor (14).

Within the pulpal floor region, the current results showed that misfit was significantly greater in the 22-degree taper group compared to the 6- and 10-degree groups. A similar trend of increasing misfit with increasing taper was observed at the axio-pulpal line angle, where the 22-degree taper group exhibited greater misfit compared to the 6-degree group. This observation is consistent with the findings of Darwish et al. (20), who reported that a smaller taper enhances pulpal adaptation, likely due to increased geometric compatibility between the prepared cavity and the milling bur. In preparations with minimal taper, the internal contours more closely match the cylindrical shape of the milling bur, potentially resulting in better adaptation. However, the literature presents some conflicting evidence. For instance, Emtair et al. (21) found that a 22-degree taper resulted in superior pulpal floor adaptation compared to 6- and 12-degree tapers. Similarly, Hajimahmoudi et al. (19) reported that a 10-degree taper offered better internal adaptation than a 5-degree taper. These discrepancies may be attributed to several factors, including variations in the overall design of the preparation, differences in the method of evaluating adaptation, or the specific type of restoration and material used in endocrown fabrication.

In the present study, the 6-degree taper group showed a significantly higher marginal misfit compared to the 10- and 22-degree groups. This finding aligns with the results of previous investigations (19,21), suggesting that increased taper improves marginal adaptation. The improvement in fit with greater taper may be due to several interrelated factors. First, increasing the taper reduces frictional resistance during the seating of restoration, allowing it to fully settle into the cavity without being impeded by binding forces. Second, more divergent walls provide better optical access for the scanner, enhancing the accuracy of digital impressions. Third, greater taper simplifies the milling and additive fabrication processes by reducing tool path restrictions and minimizing discrepancies between the restoration's internal geometry and the tool's cutting or layering path. Altogether, these factors can contribute to a more precise marginal adaptation when higher taper angles are used in the preparation design.

In contrast to the significant differences observed in other regions, the axial wall misfit did not differ significantly among the three taper groups. This finding is consistent with the results reported by Hajimahmoudi et al. (19), who also found no significant impact of axial taper on the adaptation along the axial walls. A possible explanation for this observation lies in the relatively uniform geometry and orientation of axial walls across different taper angles, which may contribute to a more predictable and consistent fit regardless of the degree of taper. Since the axial surfaces are generally less complex in shape and are located along the vertical planes of the preparation, they are less affected by factors such as scanner depth limitations or tool accessibility during

Table 2. Mean standard deviation (SD) of adjustment frequency (Number) and adjustment time (in seconds) among different taper groups

Groups	Frequency of adjustments	Adjustment time
	Mean ± SD	Mean ± SD
6° taper	2.92 ± 1.09 [a]	511.75 ±1 90.79 [a]
10° taper	2.17 ± 0.39 [b]	392.92 ± 90.25 [a]
22° taper	0.17 ± 0.39 [c]	30.17 ± 70.56 [b]
P value	< 0.001*	< 0.001*

Different superscript letters indicate significant differences between groups at P<0.05.

milling or printing. Furthermore, the axial walls typically exhibit smoother and more continuous surfaces, which facilitate accurate data acquisition during digital scanning and consistent layering during 3D printing, irrespective of the taper angle. As a result, the adaptation along these surfaces remains relatively stable despite variations in the overall taper of the preparation.

One clinically important factor when determining the optimal taper for endocrown preparation is the chairside time, as it directly affects clinical efficiency and patient comfort. In the present study, this aspect was assessed through the number of times the restoration required adjustment and the total time spent to perform those adjustments. The results demonstrated that increasing the axial taper from 6° to 22° led to a statistically significant reduction in both the frequency and duration of adjustments. This reduction may be explained by several underlying factors. As the taper increases, the internal geometry of the preparation becomes less constricted, minimizing areas of friction or binding during seating. A wider taper creates a more accessible path of insertion, allowing the restoration to seat more passively and reducing the chance of incomplete seating or over-retention. Additionally, more divergent walls reduce the likelihood of scanner inaccuracy caused by shadowing or poor depth resolution, which is especially important in additive manufacturing. The present findings are consistent with Hajimahmoudi et al (19), who reported that greater taper facilitates better scanning and milling outcomes, ultimately reducing the need for time-consuming modifications during the clinical try-in phase.

This study is not without limitations. The replica technique used is inherently two-dimensional and restricts the number and scope of evaluated areas when compared to more advanced three-dimensional analysis techniques. Additionally, this method is technique-sensitive and may be affected by the dimensional stability of the impression material, the examiner's skill, and the magnification level employed. Moreover, misfit measurements were limited to specific points and may not fully represent adaptation across the entire restoration. As this study was conducted in vitro, the findings should be interpreted with caution and may not be simply generalizable to clinical practice. Future research should include evaluations using other types of ceramics and in vivo clinical trials to generate more clinically relevant data about the effect of internal taper on the adaptation and performance of endocrowns.

Conclusions

Within the limitations of this in vitro study, it can be concluded that all three taper angles (6°, 10°, and 22°) produced misfit values within clinically acceptable ranges. An increase in taper from 6° to 22° significantly improved marginal adaptation and reduced both the frequency and duration of clinical adjustments, indicating enhanced seating efficiency. However, this improvement came at the cost of reduced adaptation at the pulpal floor, suggesting a trade-off between achieving optimal marginal fit and maintaining precise internal adaptation in deeper regions of the preparation.

Acknowledgments

None to report.

Conflict of interest

All authors declare that they have no conflict of interest.

Author contributions

M.Z. and M.A. contributed to the research design and implementation; N.Y. contributed to the research implementation, data analysis and writing of the manuscript, and N.K. contributed to the research supervision, data gathering, and writing of the manuscript. All authors read and approved the final manuscript.

Ethical approval

The study protocol was approved by the ethics committee of the Tehran University of Medical Sciences under the code IR.TUMS.DENTISTRY.REC.1398.065.

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