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# Marginal fit of endocrowns fabricated by three-dimensional printing and the conventional method: An *in vitro* study

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## ABSTRACT

**Background:** Marginal fit is a key factor in success of prosthetic restorations. This study aimed to assess and compare the marginal fit of endocrowns fabricated by three-dimensional (3D) printing and the conventional method.
**Materials and Methods:** This *in vitro*, experimental study evaluated 20 endocrowns, of which 10 were fabricated by 3D printing and 10 were fabricated by the conventional wax-up technique. The marginal gap was measured at 8 points under a stereomicroscope. The results were analyzed using the Shapiro–Wilk test, paired *t*-test, independent *t*-test, and one-way analysis of variance ($\alpha = 0.05$).
**Results:** The mean marginal gap was maximum at the distal point, and minimum at the buccal point for the conventionally fabricated endocrowns with an overall mean marginal gap of $99.67 \pm 4.59$ µm. The mean marginal gap was maximum at the mesiobuccal and minimum at the buccal point before pressing (overall mean of $103.92 \pm 2.19$ µm) before pressing, and maximum at the distobuccal and minimum at the mesiobuccal point after pressing (overall mean of $117.67 \pm 2.87$ µm). According to paired *t*-test, the mean marginal gap of endocrowns fabricated by 3D printing significantly increased after pressing at all 8 points and also in general, compared with before pressing ($P < 0.001$). Furthermore, the mean marginal gap at all points was significantly greater in endocrowns fabricated by 3D printing compared with those fabricated by the conventional method (independent *t*-test, $P < 0.001$).
**Conclusion:** Within the limitations of this *in vitro* study, the results showed that endocrowns fabricated by the conventional method had significantly superior marginal fit than those fabricated by 3D printing.

**Key Words:** Dental marginal adaptation, dental prosthesis, printing, three-dimensional

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## INTRODUCTION

Endodontically treated teeth are more susceptible to fracture since they have lost a great portion of their structure. Thus, the gold-standard treatment for endodontically treated teeth should be minimally invasive, and preserve the maximum tooth structure. Accordingly, endocrowns are now extensively used for restoration of endodontically treated teeth.[1]

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Marginal fit is an important parameter in long-term success of prosthetic restorations. Marginal fit is influenced by a number of clinical and laboratory factors such as the preparation design, impression material, impression technique, the material used for the fabrication of wax pattern, and the material and technique of casting.[2] Marginal fit is a key factor in success of



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endocrowns as well. A large marginal gap is associated with complications such as greater plaque accumulation, pulpal and periodontal inflammation, development of secondary caries, and even bone loss.[3-5] Marginal gap refers to the distance between the restoration margin and the prepared tooth surface, which is measured under a stereomicroscope and reported in micrometers (µm). At present, laser, micro-computed tomography, and cone-beam computed tomography are also used for measurement of marginal gap. Marginal discrepancy refers to the vertical distance between the internal surface of restoration margin and the finish line. According to the literature, marginal discrepancy <120 µm is considered clinically acceptable.[1,6]

Dental applications of digital technology are on the rise.[7,8] The computer-aided design (CAD) and computer-aided manufacturing technology is increasingly used for the fabrication of fixed and removable partial dentures, with promising results. Furthermore, the three-dimensional (3D) printing technology which is extensively used in industries as well as the medical field[9,10] is now used for dental purposes such as the fabrication of fixed and removal partial dentures, orthodontic appliances, maxillofacial prostheses, and dental implants.[11-23] The 3D printing technology has advantages over the conventional technique for the fabrication of dental restorations such as high accuracy, and the ability to save the data and repeat the process of fabrication, if required.[24,25] The main advantage of the 3D printing technology is the lower cost and lower rate of errors and subsequently higher efficiency. In this technique, 3D dental restorations are fabricated by the layering technique, consuming less material.[26-28]

Endocrowns refer to all-ceramic restorations that extend into the pulp chamber and receive macromechanical retention from the pulpal walls and micromechanical retention from the adhesive cement.[4,29] Endocrowns have advantages over post and core restorations and full crowns such as higher esthetics, superior mechanical properties due to the advances in bonding agents, lower cost and time, easy fabrication, and serving as a suitable alternative for restoration of teeth with short crowns or severely curved roots or obstructions that prevent the fabrication of intracanal posts.[1,29] Another advantage of endocrowns is the reduction of stress generated in the enamel, dentin, and cementum, due to their mono-block nature and consequently high fracture resistance.[29]

Lithium disilicate is available in two forms of IPS e.max press and IPS e.max CAD, which are widely used for the fabrication of full or partial coverage crowns. Lithium disilicate is a relatively high-strength glass-ceramic. The aforementioned two types have slight differences in composition. Investigations of this glass-ceramic have shown promising results.[30]

The 3D printing technique can be used for quick fabrication of different types of crowns with high accuracy.[31] Materials used in the 3D printing technique lead to the fabrication of highly resistant precise casts.[25,32]

Considering the significance of marginal fit of restorations in their long-term success, and the need for maximum preservation of tooth structure in endodontically treated teeth,[33] as well as the availability of novel digital fabrication techniques and the gap of information regarding their efficacy, this study aimed to compare the marginal fit of endocrowns fabricated by 3D printing and the conventional technique. The null hypothesis was that no difference would be found in the marginal fit of endocrowns fabricated by 3D printing and the conventional technique.

## MATERIALS AND METHODS

This *in vitro*, experimental study was conducted on 20 endocrowns [Figure 1]. The sample size was calculated to be 10 specimens in each group considering alpha = 0.05, beta = 0.2, and study power of 80% for detection of a difference 30% higher than the standard deviation. The study was approved by the Ethics Committee of Islamic Azad University, School of Dentistry, Khorasgan Branch (23810201962081).

A cavity with 3-mm depth and shoulder finish line with 1.2–1.5-mm width was created in a model of molar tooth using a laboratory carbide bur under a

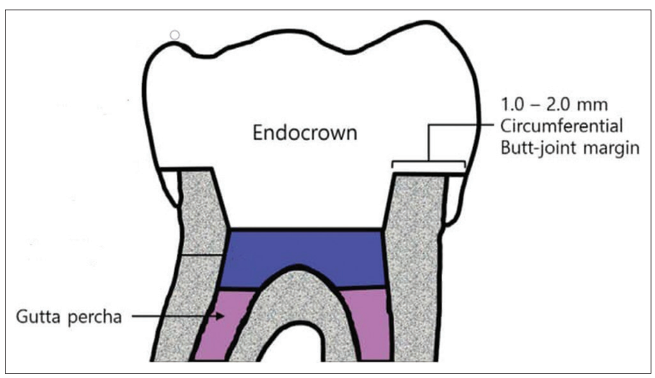


**Figure 1:** Schematic view of an endocrown.

surveyor (to ensure standardized depth and taper). The designed model was then duplicated using agar impression material, flasked, and cast with cobalt-chromium alloy (to prevent scratching of finish line). After final polishing, vertical guide lines were created with a 1.3-mm disc 1.5 mm apical to the finish line to standardize the measurement points. The measurement points were at the mid-buccal, mid-mesial, mid-distal, mid-lingual, and all four line-angles. The reference model was then mounted in auto-polymerizing acrylic resin, and depressions were created by round and fissure burs in the acrylic resin to create a key way for correct seating of the tray.

For the fabrication of special tray with 3-mm space,[34] the reference model was waxed up using the dipping technique and Plaque Photo sheets (Plaque Photo, Germany). The sheets were adapted on the key way in the acrylic resin to create keys for correct path of insertion of tray and achieve equal thickness of impression material in all areas, such that the tray and acrylic resin contacted at the stops.

One layer of tray adhesive (Haftlack; Panasil, Kettenbach, Germany) was applied into the tray, and after its setting as recommended by the manufacturer at 23°C,[35] polyvinyl siloxane impression material was applied into the tray (Contact Panasil Tray Soft Heavy and Panasil Initial, Kettenbach, Germany) and the tray was placed over the model such that the key and keyway completely matched. The tray was removed after completion of the setting time of impression material as recommended by the manufacturer. The impressions were poured with Type IV dental stone (Fuji Rock Epremium, GC, Japan), and one of them was scanned by a laboratory scanner (D750; 3Shape, Denmark). A crown framework with 20-µm cement space with margins 1 mm above the finish line was designed by its software (Dental System; 3Shape, Denmark) and transferred to the 3D printer for fabrication. Ten frameworks were fabricated by the 3D printer with resin (SuperCast ASIGA) with 10-µm thickness of each layer (Max UV; ASIGA, Australia).

To fabricate 10 waxed up frameworks by the conventional technique, first, two layers of die spacer (master; Renfert, Germany) with 10-µm thickness were applied, and then, the dies were manually waxed up. For this purpose, Hotty LED and Geo Dip green (Renfert, Germany) was applied as the first layer of wax and then GEO string wax (Renfert, Germany) was applied to complete the wax pattern.

The frameworks obtained by 3D printing and the conventional wax-up technique were flasked using investment gypsum (press 1 vest speed; Ivoclar Vivadent, Germany) according to the manufacturer's instructions. After wax burnout in a furnace (EP3000; Ivoclar Vivadent, Germany), they were pressed using e. max ingot (Ivoclar Vivadent, Germany) as recommended by the manufacturer.

Fit Checker (Fit Checker Advanced; GC, Japan) was then applied into the frameworks and they were seated on the die fixed by a clip and inspected under a stereomicroscope (SZX16, Olympus, Japan) equipped with a camera (DP27, Olympus, Japan). The marginal gap of each framework was measured at the aforementioned 8 points using a software (Cellsens Standard; Olympus, Japan) [Figure 2].

### Statistical analysis

The results were analyzed using SPSS version 22 (SPSS Inc., Chicago, IL, USA) via the Shapiro–Wilk test (for assessment of data distribution), paired *t*-test, independent *t*-test, and one-way analysis of variance (ANOVA). $P < 0.05$ was considered statistically significant.

## RESULTS

Table 1 shows the mean marginal gap of conventionally fabricated endocrowns at different points. As shown, the mean marginal gap was maximum at the distal point, and minimum at the buccal point. The overall mean marginal gap of conventionally fabricated endocrowns was 99.67 ± 4.59 µm.

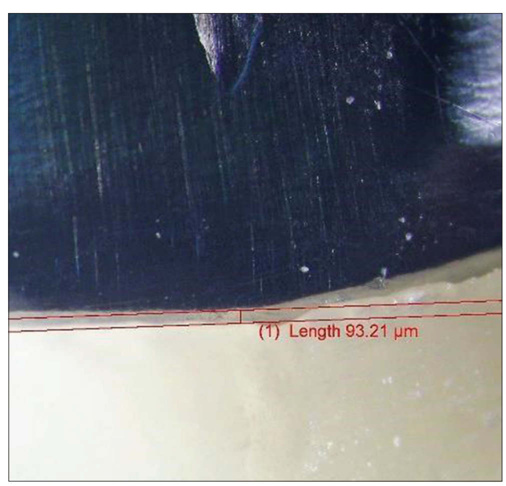


**Figure 2:** Measuring the marginal gap under a stereomicroscope (×10 magnification).

Table 2 compares the marginal gap of endocrowns fabricated by 3D printing before and after pressing at different points. Before pressing, the mean marginal gap was maximum at the mesiobuccal and minimum at the buccal point. The overall mean marginal gap of endocrowns fabricated by 3D printing was 103.92 ± 2.19 µm before pressing. After pressing, the mean marginal gap was maximum at the distobuccal and minimum at the mesiobuccal point. The overall mean marginal gap of endocrowns fabricated by 3D printing was 117.67 ± 2.87 µm after pressing.

### Comparison of the mean marginal gap of endocrowns fabricated by three-dimensional printing before and after pressing

As shown in Table 2, the mean marginal gap increased at all points after pressing compared with before. Minimum increase was noted at the mesiobuccal point (10.75 µm) while maximum increase was noted at the buccal point (15.74 µm). Paired $t$-test revealed a significant difference in the mean marginal gap at all 8 points and also in total before and after pressing ($P < 0.001$), and the values significantly increased after pressing ($P < 0.001$).

Table 3 compares the mean marginal gap of endocrowns fabricated by 3D printing and the conventional method at 8 points using paired $t$-test. As shown, the mean gap at all points was significantly greater in endocrowns fabricated by 3D printing compared with the conventional method (independent $t$-test, $P < 0.001$). This difference was minimum at the distal (12.45 µm) and maximum at the buccal point (24.40 µm).

One-way ANOVA was used to compare the marginal gap between the 8 points within each group, which revealed no significant difference in neither the conventionally fabricated endocrowns ($P = 0.119$) nor in those fabricated by 3D printing ($P = 0.938$).

## DISCUSSION

This study assessed and compared the marginal fit of endocrowns fabricated by 3D printing and the conventional method. The results revealed a significantly greater marginal gap in endocrowns fabricated by 3D printing. Thus, the null hypothesis of the study regarding absence of a significant difference in marginal gap between endocrowns fabricated by the two methods was refuted. However, it should be noted that marginal fit of both groups was within the clinically acceptable range (<120 µm).[1,6] Furthermore, comparison of the marginal gap of endocrowns fabricated by 3D printing before and after pressing revealed a significant increase in marginal gap at all points after pressing.

Our results regarding the superiority of the marginal fit of endocrowns fabricated by the conventional

**Table 1: Mean marginal gap of conventionally fabricated endocrowns at different points (*n*=10) (µm)**

| Point | Minimum | Maximum | Mean±SD |
|---|---|---|---|
| Buccal | 77.65 | 107.72 | 93.85±9.34 |
| Lingual | 86.27 | 106.27 | 96.10±7.29 |
| Mesial | 89.37 | 109.48 | 100.16±6.78 |
| Distal | 89.66 | 131.59 | 104.15±15.13 |
| Mesiolingual | 88.04 | 111.03 | 99.42±8.15 |
| Distolingual | 90.77 | 114.03 | 103.24±7.07 |
| Distobuccal | 88.45 | 107.51 | 97.72±6.50 |
| Mesiobuccal | 92.27 | 112.04 | 102.72±6.69 |
| Total | 96.25 | 105.41 | 99.67±4.59 |

SD: Standard deviation

**Table 2: Comparison of the marginal gap of endocrowns fabricated by three-dimensional printing at different points before and after pressing (µm)**

| Point | Mean±SD | | Mean difference | *t* | *P* |
|---|---|---|---|---|---|
| | Before pressing | After pressing | | | |
| Buccal | 102.50±5.92 | 118.24±8.53 | 15.74 | 10.827 | <0.001 |
| Lingual | 104.10±4.10 | 116.78±3.86 | 12.68 | 15.743 | <0.001 |
| Mesial | 103.20±7.76 | 117.29±7.73 | 14.09 | 34.165 | <0.001 |
| Distal | 103.62±5.69 | 116.59±6.11 | 12.98 | 8.709 | <0.001 |
| Mesiolingual | 103.25±5.15 | 117.86±5.85 | 14.61 | 21.593 | <0.001 |
| Distolingual | 104.10±4.66 | 118.65±4.48 | 14.55 | 20.314 | <0.001 |
| Distobuccal | 105.10±5.92 | 119.75±7.46 | 14.65 | 21.760 | <0.001 |
| Mesiobuccal | 105.45±5.96 | 116.20±7.03 | 10.75 | 4.976 | 0.001 |
| Total | 103.92±2.19 | 117.67±2.87 | 13.75 | 26.461 | <0.001 |

SD: Standard deviation

**Table 3: Mean marginal gap of endocrowns (µm) fabricated by three-dimensional printing and the conventional method at 8 points using paired *t*-test**

| Point | Mean±SD | | Mean difference | *t* | *P* |
|---|---|---|---|---|---|
| | Conventional | After pressing | | | |
| Buccal | 93.85±9.34 | 118.24±8.53 | 24.40 | 6.099 | <0.001 |
| Lingual | 96.10±7.29 | 116.78±3.86 | 20.68 | 7.929 | <0.001 |
| Mesial | 100.16±6.78 | 117.29±7.73 | 17.12 | 5.267 | <0.001 |
| Distal | 104.15±15.13 | 116.59±6.11 | 12.45 | 2.412 | 0.027 |
| Mesiolingual | 99.42±8.15 | 117.86±5.85 | 18.44 | 5.810 | <0.001 |
| Distolingual | 103.24±7.07 | 118.65±4.48 | 15.41 | 5.822 | <0.001 |
| Distobuccal | 97.72±6.50 | 119.75±7.46 | 22.03 | 7.041 | <0.001 |
| Mesiobuccal | 102.72±6.69 | 116.20±7.03 | 13.48 | 4.393 | 0.001 |
| Total | 99.67±2.59 | 117.67±2.87 | 18.00 | 14.733 | <0.001 |

SD: Standard deviation

method compared with 3D printing were in agreement with the findings of Eftekhar Ashtiani *et al*.[36] and Rages.[37] Eftekhar Ashtiani *et al*.[36] evaluated the marginal fit of inlays fabricated by the conventional method and 3D printing and reported that the mean marginal gap was 82.6 µm in the conventional and 104 µm in the 3D printing group. Their results were in line with our findings, although the type of crown fabricated in their study and the 3D printer used were different from our study. Rages[37] assessed the marginal fit of zirconia crowns and reported the mean marginal gap of 68 µm in the conventional and 73.7 µm in the 3D printing group, which also confirmed the superiority of the conventional method.

Variations in the reported marginal gap values in different studies can be due to differences in the type of scanner, type of printer, method of measurement of marginal gap, and technician errors in different steps such as the fabrication of gypsum die or wax pattern, or injection of ceramic ingots, different commercial brands of ingots and investment material, type and commercial brand of impression material, and different type of fabricated restorations.

Several methods have been used for assessment of marginal fit of restorations in the literature such as the optical microscope,[38] scanning electron microscope,[39] or the silicone replica technique.[40] In this study, a stereomicroscope was used for this purpose since a systemic review by Nawafleh *et al*.[41] reported that the direct-viewing technique by using a microscope is the most common method of assessment of marginal fit.

The advantages of this study compared with previous investigations were the larger sample size, as well as the fact that marginal gap was evaluated both before and after pressing in 3D printing group. Poorer marginal fit in endocrowns fabricated by 3D printing may be due to the following reasons: (I) elimination of resin may be harder than wax and (II) since fabrication of crowns with 10-µm thick layers is time consuming, temperature rise of the curing lamp may decrease the efficiency and lead to incomplete curing of layers. Decreasing the thickness of increments during printing may improve the marginal fit. However, this topic requires further investigations.

*In vitro* design was a limitation of this study, which limits the generalization of results to the clinical setting. Furthermore, the possibility of technician's error in correct identification of finish line, possible errors in manual wax-up and placement of die spacer, and possible errors in the casting process might have affected the marginal fit, which should be addressed in future studies.

Future studies are required to measure the marginal gap at a higher number of points in each group to minimize the effect of errors in the process of fabrication and measurement on the results. Since errors may occur at any step of the procedure, the marginal gap of crowns fabricated by 3D printing should be measured before and after casting to find out at what step of the way errors occur (for example, errors may occur in the printing or wax burnout steps). Furthermore, it should be evaluated whether decreasing the thickness of printed layers can increase the marginal fit or not.

## CONCLUSION

Within the limitations of this *in vitro* study, the results showed that endocrowns fabricated by the conventional method had significantly superior marginal fit compared with those fabricated by 3D printing.


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### Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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