Comparison of wear of interim crowns in accordance with the build angle of digital light processing 3-dimensional printing: A pilot in vivo study

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Abstract

Background: There are still insufficient studies of the relationship between the clinical wear and build angle of the interim crowns fabricated with the DLP 3D printing. The purpose of this study was to evaluate the wear volume in the interim crown fabricated according to the printing angle of DLP 3D printing.

Methods: This study included five patients who needed the single crown in the mandible molar. Interim crowns were fabricated directly in the oral cavity with the conventional method. Using a DLP 3D printer, the crowns were fabricated by setting the angles to 0, 45, and 90 degrees. Four fabricated interim crowns, using the conventional method, were randomly delivered to the patients, and used respectively for one week. The intaglio surface of interim crowns before and after use were scanned with a 3D scanner. In addition, volume changes before and after use were measured, and 3D height changes of the occlusal surface were evaluated by calculating the RMS value. Statistical analysis verified the data normality, and each group's wear volume was evaluated, using One-way ANOVA and Tukey HSD test (α = 0.05).

Results: The value was significantly higher at 90 degrees compared to the conventional method and 0 degrees (P < 0.05). There were significantly higher volume change values at 90 degrees compared to the conventional method (P < 0.05). In addition, the interim crowns fabricated with the conventional method showed the lowest changes in the RMS and volume values (P < 0.05).

Conclusions: The 90 degrees printing angle is not recommended when interim crowns are fabricated with the DLP 3D printing method.

Trial registration: The study protocol was approved by the Kyungpook National University Dental Hospital Institutional Review Board (approval number: KNUDH-2021-11-02-01).

Background

For a successful prosthetic restoration, the interim crowns’ role is important. The interim crowns provide functions, including proper maintenance of the occlusal relationship, prevention of tooth movement, and protection of the dental pulp and periodontal tissue [1, 2]. Appropriate wear resistance of the interim crowns is required for these functions’ maintenance. If wear is excessive, there may be a change in the functionality in masticatory movement as the occlusal vertical dimension becomes lower. In addition, the masticatory efficiency may fall, and premature contact may appear in the anterior teeth [3].

The conventional method directly manufactures the interim crowns in the oral cavity.4 Still, during the production process, high ratios of contraction and heat take place, and the mechanical characteristic is also lacking compared to the production method by milling [5–7]. In contrast, the indirect method using CAD/CAM technologies (the production method by milling) has superior wear and flexure strength [8], shorter chair time, and superior marginal and internal fit compared to the conventional method [7]. Recently, studies of producing interim crowns with 3D printing, a laminating processing method, have
actively been conducted. Of them, SLA and DLP methods are representative [9]. The SLA method has strengths of high precision and smooth surface finish, etc. [10], while the areas in which the DLP method is utilized gradually become broader in the dental chairside field as it has a faster printing speed than the SLA method by hardening a layer at once, dental chairside field [11].

There are various study results of wear of DLP printed interim crowns. Studies show that wear resistance is weaker in the conventional, the milling, and SLA methods [12, 13], the same [5, 14], or the better [15, 16]. Most of these studies of wear of interim crowns were conducted in vitro using a mastication simulator, instead of in vivo, since it is difficult to control various variables [16]. In the mastication simulator, various elements are reflected, such as force, sliding distance, testing medium, pH-cycling, and temperature cycling to imitate the oral cavity’s masticatory system [17]. However, since wear is not a simple material property but a system property coming from complex interactions of various factors [14], there is a limitation in reproducing that with an in vitro study [17]. Previous studies showed that there was a significant difference in the wear of the temporary crowns fabricated with the milling method between the in vitro and in vivo methods [18]. Thus, the clinical wear verification of the 3D-printed interim crowns in the oral cavity must be conducted.

Meanwhile, in the DLP method, the restoration’s mechanical properties are affected by build orientation [19]. Differing physical properties according to the printing angle are called anisotropy. Various physical properties of anisotropy have been reported, such as marginal and internal fit [7, 20], surface roughness [21], flexural strength [22], and the optimum printing angle according to each characteristic is also recommended. Yet, there are few wear studies. A previous study noted that there was no relationship between wear behavior and build orientation in the DLP-printed cylinder-shaped specimen [23]. However, there are still insufficient studies of the relationship between the clinical wear and build angle of the interim crowns fabricated with the DLP method, using dental materials.

Thus, the purpose of this study was to evaluate wear volume according to the build angles of the DLP-printed interim crowns printed (0, 45, and 90 degrees). The null hypothesis of this study was that there is no relationship between wear and build angle of the DLP 3D-printed interim crown.

**Methods**

This clinical study was performed in accordance with the approval of Kyungpook National University Dental Hospital Institutional Review Board (approval number: KNUDH-2021-11-02-01) (Fig. 1). The informed consent was obtained from all subjects. Of the patients who visited the Department of Prosthodontics, Kyungpook National University Dental Hospital and need single crown treatment, those who wanted to participate in the present study were recruited. The selection criteria are as follows: (1) patients who need single restoration treatment in mandible molar teeth; (2) those without decay or periodontal abnormalities in the abutment tooth; (3) those without any occlusal problems. In addition, the following patients were excluded since there was a possible impact on wear or possibility of a side effect according to the experiment: (1) patients with the restoration of antagonist teeth; (2) those with a
possible crack tooth; and (3) those with bruxism or clenching habit. This study recruited a total of six patients, considering a 20% dropout rate. One participant was dropped out because of frequent fracture of the temporary tooth.

On Day 1 of visit, the mandible molar teeth were prepared by one skilled technician, using a diamond bur (102R bur, Shofu, Kyoto, Japan). In tooth preparation, the margin shape was formed as a supragingival chamfer margin, and the occlusal surface was excised at 1.5 mm in thickness. Then, one skilled operator took a virtual working cast of the abutment tooth, proximal teeth, and antagonist teeth, and took an occlusal scan, using an intraoral scanner (CS3600; Carestream Dental, Rochester, NY, USA).

Immediately after tooth preparation, interim crowns were fabricated, using self-cured resin (Unifast III; GC Corporation, Tokyo, Japan) with the conventional direct method on the chairside (Table 1). In all groups, the occlusal adjustment process and the final polishing process were performed in the same process by a skilled clinician. The interim crowns were polished with a silicon carbide paper of 600- and 1200-grit grain sizes on a rotary machine with water cooling. Whether the occlusal point and height were appropriate was checked with a 21-um-thick check bite (Check-Film II - Red/Black; Caicedo Group Inc, USA) and an 8-µm-thick shimstock (ARI SHIMSTOCK; TAEKWANG, Seoul, Korea). Immediately before cementation after the final polishing process, the interim crown's surface was extraorally scanned, using an intraoral scanner (CS3600, Carestream Dental, Rochester, NY, USA). The patients were asked to use temporary cementation (Temp-bond NE, Kerr, Orange, CA, USA) for one week, and to be careful about sticky or hard foods that might cause fall or fracture of the interim crown.

<table>
<thead>
<tr>
<th>Group</th>
<th>Product name</th>
<th>Method</th>
<th>Manufacturer</th>
<th>LOT Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional group</td>
<td>UNIFAST III</td>
<td>self-cured</td>
<td>GC corporation, Tokyo, Japan</td>
<td>2004171</td>
</tr>
<tr>
<td>3D printing group</td>
<td>RAYDENT C&amp;B</td>
<td>DLP 3D printing</td>
<td>Ray Co., Ltd., Hwaseong-si, Korea</td>
<td>RCB209082B</td>
</tr>
</tbody>
</table>

The acquired virtual working cast was exported in the STL format, using the intraoral scanner. In addition, with the CAD software (3Shape Dental Designer; 3Shape A/S), interim crowns were designed in the following condition: 60-µm cement space. After the CAD process, the virtual interim crowns were exported with STL, and in the 3D printer software (Megagen, Daegu, Korea), the build angles for printing were set to 0, 45, and 90 degrees (Fig. 2). 3D printing support was set to the software-recommended value. In addition, crowns were printed, using a DLP 3D printer (MEG-PRINTER 3D II; Megagen, Daegu, Korea), under the following conditions (Table 1): 50-µm XY resolution, 50-µm layer thickness. A resin (Raydent C&B; Ray Co., LTD., Hwaseong-si, Korea) was selected as the 3D printing material. The printed interim crowns went through the washing and post-curing process according to the manufacturer's recommendations and were stored in distilled water at 37 degrees until cementation.
The patients revisited the hospital one week after the first interim crown use. The existing interim crown was removed, and the surface was extraorally scanned with an intraoral scanner (CS3600, Carestream Dental, Rochester, NY, USA).

In addition, the patients were provided with a new interim crown randomly selected from the printing angles of 0, 45, and 90 degrees. They went through the relining, occlusal adjustment, and polishing steps in the oral cavity. For relining, a self-cured resin (Unifast III, GC Korea, Seoul, Korea) was employed. Before use, the interim crown's surface was scanned. The patients lived with the new interim crown for one week. In addition, in the next hospital visit, the existing interim crown's surface was scanned, and one of the remaining interim crowns was provided in random order.

Repeating these processes, the patients used four crowns (conventional method, n = 1; 3D printing method, n = 3) respectively for one week in one month. The interim crowns’ surface before and after use was scanned. Lastly, the technician took the final impression and set the final prosthesis.

Using the 3D inspection software (Geomagic Control X, 3Dsystems, Cary, NC, USA), STL file changes of the interim crowns before and after wear were imported (Fig. 3). The interim crowns’ volume and height were observed. The interim crown before wear was designated as a reference, and the best-fit alignment of those after wear was made based on the interim crown’s outer surface area, excluding the occlusal surface area before wear (Fig. 3). To verify the coincidence of the outer surface area in which interim crowns overlapped before and after wear, it was evaluated in 3D inspection software (Geomagic Control X, 3Dsystems, Cary, NC, USA), and it was found that the two models’ overlapping areas had very high coincidence (3.60 ± 0.80 µm). Through the volume comparison before and after wear, the volume loss was calculated. In addition, the data pointers’ interval before and after wear was calculated through the root mean square (RMS) value (Fig. 3), and the formula is as follows.

\[
RMS = \frac{1}{\sqrt{n}} \cdot \sqrt{\sum_{i=1}^{n} (X_{1,i} - X_{2,i})^2}
\]

\(X_{1,i}\) means the interim crown’s point cloud before wear, \(X_{2,i}\) the point cloud after wear, which means the three-dimensional position of the \(i^{th}\) measurement point. \(n\) means the number of all point clouds evaluated.

The RMS value shows how different the deviation between two different data sets is from 0. Thus, a low RMS value shows a high degree of three-dimensional agreement of the overlapped data. In addition, a 3D comparison was shown with a color difference map, and the range of −100 µm and the tolerance range of −10 µm were designated (green).

Statistical analysis used in this study was conducted, using SPSS Statistics (IBM Co., Armonk, NY, USA). First of all, through the Shapiro-Wilk test, the normal data distribution was investigated. In addition, since
normal distribution is formed, each group's wear volume was compared with a one-way ANOVA test, and as ex-post analysis, using the Tukey HSD test (α = 0.05).

**Results**

Between the groups, there were significant differences in RMS value (P = 0.002; Table 2; Fig. 4), and compared to the conventional method (11.88 ± 2.69 µm) and 0 degrees (12.14 ± 2.38 µm), the RMS value showed significantly higher at 90 degrees (16.46 ± 2.39 µm) (P < 0.05; Table 2; Fig. 4). Likewise, there was a significant difference in the groups' volume change (P = 0.002; Table 3; Fig. 4), and there was a significantly higher volume change value at 90 degrees (1.74 ± 0.41 mm³), compared to the conventional method (0.70 ± 0.15 mm³) (P < 0.05; Table 3; Fig. 4). In addition, the interim crown fabricated with the conventional method showed significantly lower RMS and volume change values, compared to those with the 3D printing group (P < 0.05; Tables 2 and 3; Fig. 4).

<table>
<thead>
<tr>
<th>Building angle</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>95% Confidential interval</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Comparison**</th>
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</thead>
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<td>Conventional method</td>
<td>5</td>
<td>11.88</td>
<td>2.69</td>
<td>8.53</td>
<td>7.70</td>
<td>14.80</td>
<td>A</td>
</tr>
<tr>
<td>0 degrees</td>
<td>5</td>
<td>12.14</td>
<td>2.38</td>
<td>9.17</td>
<td>9.7</td>
<td>15.50</td>
<td>A</td>
</tr>
<tr>
<td>45 degrees</td>
<td>5</td>
<td>13.78</td>
<td>1.29</td>
<td>12.17</td>
<td>11.80</td>
<td>15.10</td>
<td>AB</td>
</tr>
<tr>
<td>90 degrees</td>
<td>5</td>
<td>16.46</td>
<td>2.39</td>
<td>13.49</td>
<td>13.20</td>
<td>18.90</td>
<td>B</td>
</tr>
<tr>
<td>F</td>
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<td>4.363</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>P</td>
<td></td>
<td>0.02*</td>
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</table>

RMS, root mean square. *Significance determined using the One-way ANOVA, P < 0.05. **Letters determined using the Tukey HSD test, P < 0.05.
### Table 3

<table>
<thead>
<tr>
<th>Building angle</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>95% Confidential interval</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Comparison**</th>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td>Upper</td>
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<td>0.15</td>
<td>0.50</td>
<td>0.89</td>
<td>0.50</td>
<td>0.90</td>
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<tr>
<td>0 degrees</td>
<td>5</td>
<td>1.22</td>
<td>0.63</td>
<td>0.43</td>
<td>2.00</td>
<td>0.20</td>
<td>1.70</td>
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<tr>
<td>45 degrees</td>
<td>5</td>
<td>1.32</td>
<td>0.48</td>
<td>0.71</td>
<td>1.92</td>
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<td>1.90</td>
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<tr>
<td>90 degrees</td>
<td>5</td>
<td>1.74</td>
<td>0.41</td>
<td>1.22</td>
<td>2.25</td>
<td>1.30</td>
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<tr>
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<td>4.367</td>
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<tr>
<td>P</td>
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<td>0.020*</td>
<td></td>
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</table>

RMS, root mean square. *Significance determined using the One-way ANOVA, $P < 0.05$. **Letters determined using the Tukey HSD test, $P < 0.05$.

The color difference map according to the build angle showed relatively smaller wear areas in the conventional method, and in the 3D printing group, the wear areas tended to become broader from 0 to 90 degrees (Fig. 5). The wear areas in the color difference map were the same as the occlusal points found in the oral cavity.

**Discussion**

The purpose of this study was to conduct an in vivo study to examine whether there would be a wear volume difference according to the printing angle of the interim crowns using the 3D DLP method. As a result, there was a significant RMS value difference between the 3D-printed interim crowns according to the angle, while there was no wear volume difference according to the angle. However, compared to the conventional method, at 90 degrees, there was a significantly higher RMS value, and there was a higher wear volume ($P < 0.05$). Thus, the null hypothesis that there would be no wear volume difference of the interim crowns according to the printing angle was rejected.

In the present study, there was a wear difference of the interim crowns between the conventional and the 3D printing method ($P = 0.020$). Through RMS value, vertical height loss can be estimated, and through the volume loss value, the absolute wear volume can be measured. The height and wear volume of the interim crowns printed at 0 degrees for the two criteria were the smallest, while the height and volume of the interim crowns printed at 90 degrees were the largest. In other words, the more the printing angle, the more wear becomes. Differing physical properties according to the angle are called anisotropy.

A previous study reported that there was anisotropy in the 3D-printed restoration with the DLP method [19]. There were two conflicting findings concerning this. First, a finding reported that there might be a
part with weak polymerization due to the shadow area between pixels [24]. Accordingly, Monzon et al. [24] reported that the resin bar printed at 90 degrees showed superior mechanical properties in flexural modulus and flexural stress than that printed at 0 degrees. Second, on the contrary, others reported that anisotropy was caused by the bonding strength difference between the inter- and the intra-layer [11, 25]. Park et al. [11] noted that the flexural strength of the 3-unit interim bridge printed at 90 degrees showed the lowest value, and that the intra-layer bonding showed a stronger tendency than the inter-layer bonding. In addition, Kessler et al. [25] noted in a study with a bar-shaped interim material that the inter-layer was the weakest link, and the specimen printed at 90 degrees was more vulnerable to fracture. Thus, the present study’s result can be similar to the results by Park et al. [11] and Kessler et al. [25], and it is assumed that wear decreases as the printing angle lowers, and the stronger the mechanical properties became. However, to draw these conclusions, an additional study is necessary to conduct to examine the wear tendency by evaluating the physical properties.

There are two types of wear: Two-body wear caused by the direct friction between the cusps and three-body wear caused indirectly by the food between the two cusps [26]. In this study, two types of wear were also observed. Two-body wear can be seen through the interim crown’s occlusal points, and the size and number decreased after use while the present study was conducted. This is because the areas decreased where the cusps contacted each other as wear progressed, while overall occlusal vertical dimension was maintained. On the other hand, three-body wear may decrease or increase according to the debris, and the wear volume is very little, or it does not always take place [26]. In fact, in the remaining areas, excluding two-body wear points around the occlusal points, there was almost no wear in the color map (Fig. 5), and this means that, the three-body wear impact is insignificant. In addition, in the color map (Fig. 5), wear areas tend to become broader from 0 to 90 degrees. It is found again that the more the printing angle, the more wear becomes.

According to Beleidy et al. [27], there was no difference between wear analysis through 3D scanning and the optical digital profilometry, the conventional method. In addition, in the present study, the coincidence of the overlapping outer surface areas of the interim crowns before and after wear was 3.60 ± 0.80 µm, and the two models’ overlapping areas showed very high coincidence.

In the present study, there was no statistical difference in wear volume between the interim crown fabricated with the conventional method and that printed at 0 degrees ($P > 0.05$). In general, the interim crowns fabricated with the DLP method are printed at 0 degrees, and there is a study that their wear resistance was weaker than that with the conventional fabricating, milling, and SLA methods [12, 13]. On the other hand, there are also results that wear resistance was the same as [5, 14] or better than [15, 16] that with the conventional fabricating, milling, and SLA methods. And yet, even if the interim crowns were fabricated with the same method, wear might be different according to the composition of the resin material used. According to Kessler et al. [14], there were significant differences in wear among various 3D-printed materials, and products with high filler content would be recommended. In addition, the study of flexural strength experimented on three products and noted that the products’ characteristics were most important, of several factors [25]. Thus, the present study’s result should also be limited to the result
of the study of the products used. In addition, it is necessary to conduct an additional study that evaluates wear, using various products.

As an in vivo pilot study, this study has minor limitations. The present study acquired scan data, using an intraoral scanner to evaluate wear. The intraoral scanner (CS3600) employed in this study reported on the results of 8.66 ± 0.40 μm trueness and 5.44 ± 0.52 μm precision in a previous study [28]. Also, in their study of wear, Ahn et al. [16] measured wear volume with the intraoral scanner. In addition, this study employed anatomical interim crowns. If the actual printing angle was 45 degrees, the actual contact angle between the tooth and the temporary restoration might be slower or steeper than 45 degrees, considering the cusp shape and the jaw movement direction. In other words, the effect of the actual angle might be distorted from the intention. Lastly, according to each participant’s sex and age, the masticatory force difference, dietary habits, and oral habits are all different. In addition, the experiment for a short time of one week and on the single crown in the environment in which the overall occlusal vertical dimension was maintained has a limitation in the actual wear volume. Therefore, it is possible to peek at the tendency of wear volume changes according to the printing angle; however, it would be necessary to conduct a more subdivided and longer-term study to trust the absolute value of wear volume.

Conclusion

The interim crowns fabricated with the conventional method showed wear resistance similar (0 degrees) or superior than those fabricated with the DLP 3D printing method. In terms of wear resistance, the 90 degrees printing angle is not recommended when the interim crown is fabricated with the DLP 3D printing method, but the 0 degrees printing angle is recommended, instead.

Abbreviations

DLP digital light processin
3D 3-dimensional
RMS root mean square
CAD/CAM computer-aided design and computer-aided manufacturing
SLA stereolithography apparatus
STL standard tessellation language.

Declarations
Availability of data and materials

All outcome data are available as summary measures or representative images in the main text or the extended data. The raw datasets generated analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study protocol was approved by the Kyungpook National University Dental Hospital Institutional Review Board (approval number: KNUDH-2021-11-02-01). All methods were carried out in accordance with relevant guidelines and regulations. The informed consent was obtained from all subjects.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author's Contribution

H. L. and K. S. contributed to conception and design, data acquisition, analysis, and writing-original draft; D.-H. L. contributed to data acquisition and interpretation; S.-Y. K. contributed to data acquisition and interpretation; K.-B.L. contributed to supervision and project administration. All authors gave final approval and agree to be accountable for all aspects of the work.

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References


Figures
Figure 1

Study design.
**Figure 2**

DLP 3D printing’s build angle.
Figure 3


Figure 4
Root mean square and wear volume comparison according to the build angle. A: root mean square. B: wear volume. Letters (a and b) determined using the Tukey HSD test, $P < 0.05$.

Figure 5

3D wear comparison according to the build angle. A: Conventional method. B: 3D printing build angle of 0 degrees. C: 3D printing build angle of 45 degrees. D: 3D printing build angle of 90 degrees.