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# The comparison of the accuracy of temporary crowns fabricated with several 3D printers and a milling machine

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**PURPOSE.** The purpose of this *in vitro* study was to compare the accuracy of various 3D printers and a milling machine. **MATERIALS AND METHODS.** The die model was designed using CAD (Autodesk Inventor 2018 sp3). The 30 µm cement space was given to the die and the ideal crown of the mandibular left first molar was designed using CAD (ExoCAD). The crowns were produced using the milling machine (Imes-icore 250i) and the 3D printers (Zenith U, Zenith D, W11) and they were divided into four groups. In all groups, the interior of each crown was scanned (Identica blue) and superimposed (Geomagic Control X) with the previously designed die. The difference between the die and the actual crown was measured at specific points. The Kruskal-Wallis test, the Mann-Whitney test, and Bonferroni's method were performed with a statistical analysis software ($P$ < .008 in inter-group comparison $P$ < .001 in intra-group comparison). **RESULTS.** In all groups, the center of the occlusal area and the anti-rotational dimple area showed significantly greater difference and the marginal area showed the smallest difference comparatively. The mean value of the difference in each area and the sum of the differences were higher in order of W11, Imes-icore 250i, Zenith D, and Zenith U. **CONCLUSION.** The digital light processing (DLP) method shows higher accuracy compared to the sereolithography (SLA) method using the same resin material. [J Adv Prosthodont 2023;15:72-9]

**KEYWORDS**

3D printer; Additive manufacturing; CAD-CAM; Digital light processing; Temporary crown

## INTRODUCTION

3D printing, known as additive manufacturing, is the process used to build objects one layer at a time. Materials such as plastics, liquids, or powder grains are fused layer by layer until the desired products are formed. Many

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of the 3D printing processes used today were first developed in the late 1980s and 1990s. The first use of 3D printing technology in dentistry was in the late 1990s to create dental implants. In recent years, the advances in dental technology, such as CBCT and intraoral scanning, have expanded 3D printing usage. Also, various 3D printers including Stereolithography (SLA), Digital Light Processing (DLP), and Liquid Crystal Display (LCD) are being introduced in the dental industry and there are many ongoing studies on the fabrication of prosthetics using such 3D printing.[1-4] In SLA method, high-density Ultraviolet (UV) laser beam is emitted according to the planned design onto the photopolymer resin to create a thin film layer. After the first layer is formed, the pedestal moves down at regular intervals to form the second layer and eventually to complete the output.[5,6] The SLA method uses photopolymer liquid resin and it has the advantage of high precision and excellent surface roughness, but also the disadvantage of longer printing time for wider output surfaces.[7-9] In DLP method, ultraviolet rays are used in pixel unit to cure each layer because a beam projector screen is composed of pixels.[10-12] The chips with multiple micro-mirrors (DMDs) emit UV laser beams. The micro-mirrors are designed to reflect light depending on angles and thus mirrors can be selectively used.[13,14] Because the light is emitted through the lens of the beam projector, the image developed in a small hole should be magnified in great scale and then transmitted to the resin tank. This may cause pixel distortions at the edge, and therefore, large objects printed by the DLP method are less elaborate. However, the DLP method has an advantage of shorter output time since it works in surface unit whereas the SLA method works in linear unit.[15-17] The LCD method also uses light to cure layer by layer, but there is a difference that the LCD method prevents hardening by covering unnecessary parts of LCD screens with mask, while the DLP method selectively emit light only onto pixels that need to be hardened. The LCD method is safe from pixel distortion, which often occurs in DLP method because UV LCD emits light on the entire area. So, the resolution of the LCD becomes a very important factor in determining the output quality of the LCD method. The disadvantage of LCD method would be slow curing speed since the light of the LCD is weaker compared to the DLP projector. However, both methods emit light in surface unit, so they have the advantage over the SLA method in printing speed.[18,19]

In this study, we compared the accuracy of various 3D printers and a milling machine and analyzed the deviations according to the area of the specimen in each method.

## MATERIALS AND METHODS

The die model was designed using CAD (Autodesk Inventor 2018 sp3; Autodesk, San Francisco, CA, USA). The diameter of the base of the die was 8.04 mm, the diameter of the margin was 7.45 mm, the height of the base was 1.7 mm, and the height from the bottom to the point where the margin starts was 2.1 mm. The height from the bottom to the point where the axial wall starts was 3.3 mm, the height of the die was 7 mm, and the gradient of the axial wall was 6 degrees. The notch with the diameter of 2 mm was formed and the anti-rotational dimple was made on the occlusal line angle. The distance from the bottom of the notch to the center of the die was 2.6 mm (Fig. 1). The 30 μm cement space was given to the die and the ideal crown of the mandibular left first molar was designed using CAD (ExoCAD; Exocad, Darmstadt, Germany). The crowns were produced using the milling machine and the 3D printers. The crowns were divided into four groups. 20 crowns were produced using the PMMA resin (Real Fit PMMA Block; DONGYANG D.M.T,

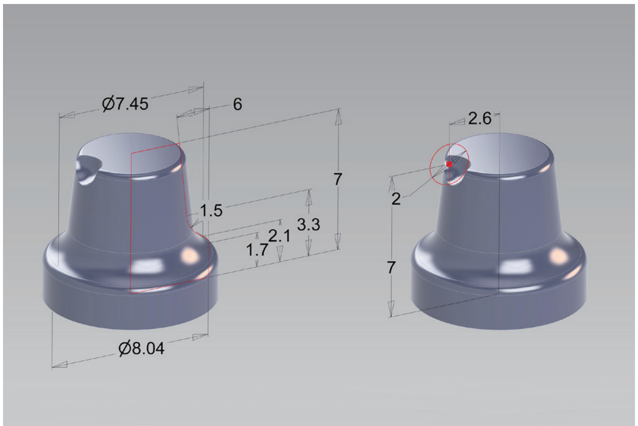


**Fig. 1.** The design of the die.

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Daegu, South Korea) by the milling machine (Imes-icore 250i; Imes-icore, Eiterfeld, Germany) and were set as the control group. 20 crowns were produced using the resin (ZMD-1000B; Dentis, Daegu, South Korea) for 3D printer by the SLA method (Zenith U; Dentis, Daegu, South Korea) and were set as the group SZ. 20 crowns were produced using the resin (ZMD-1000B; Dentis) for 3D printer by the DLP method (Zenith D; Dentis, Daegu, South Korea) and were set as group DZ. 20 specimens were produced using the resin (C&B MFH; Nextdent, Utrecht, Netherlands) for 3D printer by the DLP method (W11; BIO3D, Gimpo-si, South Korea) and were set as group DW (Table 1, Table 2). In the milling machine, auto-calibration was performed and axis alignment was completed. A new cutting tool was placed before producing the crown. In 3D printer, calibration was performed before printing and the layer thickness was set to 100 µm. According to the study by Alharbi *et al.*,[10] the highest accuracy of the SLA method was shown at the 120 degrees build. According to the studies of Osman *et al.*,[20] the highest precision of the DLP method was shown at the 135 degrees build angle. Therefore, the build angle of the support was set as 120 degrees in the SLA method and 135 degrees in the DLP method. Supporting struts were applied automatically using Zenith printer software (Zenith S/W; Dentis, Daegu, South Korea). After printing, the remained resin was removed, and the crowns were cleaned with 99.8% ethanol (Absolute ethanol; Koryo Chemical Eng., Seoul, South Korea) for 5 minutes. Next, post-curing process was performed in an ultraviolet curing unit (LC-3D Print Box; Nextdent, Utrecht, Netherlands) for 5 minutes according to the manufacturer's instruction. Then, the supporting struts were carefully removed using denture burs.

In all groups, the interior of each crown was scanned with the LED Scanner (Identica blue; MEDIT, Seoul, South Korea) and superimposed (Geomagic Control X; 3D Systems, Rock Hill, SC, USA) with the data from the previously designed die to measure the distance at specific points. The resolution of the scanner is 10 µm. Specimens were free from the light reflection during the scan process. If the scan spray was

**Table 1.** The classification of the groups

| Group | Manufacturing method | Resin |
|---|---|---|
| Control | Milling machine<br>(Imesicore 250i; Imes-icore, Eiterfeld, Germany) | PMMA resin<br>(Real Fit PMMA Block; DONGYANG D.M.T, Daegu, South Korea) |
| SZ | SLA<br>(Zenith D; Dentis, Daegu, South Korea) | UV light curing resin<br>(ZMD-1000B; Dentis, Daegu, South Korea) |
| DZ | DLP<br>(Zenith D; Dentis, Daegu, South Korea) | UV light curing resin<br>(ZMD-1000B; Dentis, Daegu, South Korea) |
| DW | DLP<br>(W11; BIO3D, Gimpo-si, South Korea) | UV light curing resin<br>(C&B MFH; Nextdent, Utrecht, Netherlands) |

**Table 2.** The specifications for the 3D printers used

| | Zenith U (SZ) | Zenith D (DZ) | W11 (DW) |
|---|---|---|---|
| Technique method | SLA | DLP | DLP |
| Light source | Blue laser | Blue LED (405 µm LED) | LED |
| Layer thickness | 16 µm, 50 µm, 100 µm | 50 µm, 100 µm | 50 - 100 µm |
| Dimension | 354 × 366 × 483 mm | 340 × 460 × 430 mm | 300 × 394 × 740 mm |
| Working area | 110 × 110 × 150 (X,Y,Z/mm) | 128 × 80 × 150 (X,Y,Z/mm) | 110 × 62 × 90 (X,Y,Z/mm) |
| X-Y resolution | N/S | 100 µm, 1280 × 720 | 100 µm, 1920 × 1080 |
| Material properties | Photopolymer resin | Photopolymer resin | Photopolymer resin |

used, errors could occur depending on the thickness change of inner surface; so we did not use the scan spray. The crown and the die did not match perfectly and showed fine difference. We thought that the margin area of the specimen could not be ideally flat. So, we demanded the engineer to overlap the margin area as much as possible. And we measured the volume of the die and the crown based on the maximum superimposed plane. We drew a virtual line connecting the center of the die and the center of the anti-rotational dimple (line A), and measured the distance between the two points where the line A and the margin of the die cross. The difference value between this data and the distance in the actual crown was recorded as Mar 0. We drew another line perpendicular to the line A, and measured the distance between the two points where the newly drawn line and the margin of the die cross. The mean difference value between this distance and the distance in the actual crown was recorded as Mar 90. We recorded the difference between the diameter of the die at the chamfer area and the corresponding value in the actual crown, as Cham. The chamfer area was determined as the area 2.7 mm above the base of the die. We recorded the difference between the diameter of the die at the axial area and the corresponding value in the actual crown, as Axial. The axial area was determined as the area 5 mm above the base of the die. We recorded the difference between the diameter of the die at the axio-occlusal area and the corresponding value in the actual crown, as Axio-occ. At this time, the anti-rotational dimple area was excluded. We recorded the difference between the diameter of the die at the anti-rotational dimple area and the corresponding value in the actual crown, as Dim. We recorded the difference between the height of die at the center of the occlusal area and the corresponding value in the actual crown, as Occ. The axio-occlusal area, the anti-rotational dimple area, and the center of the occlusal area was determined as the area 6.8 mm above the base of the die. The mean value of the difference in each area is called Compare1. Volume Cr is the volume of the inner surface of the actual crown, and Volume Di is the volume of the die. The difference between Volume Cr and Volume Di means the surface deviations (Fig. 2).

Statistical analysis was performed with statistical software (PASW Statistics 18.0; IBM Corp., Armonk, NY, USA). The normality test was conducted for inter- and intra-group comparisons. The Kolmogorov-Smirnov test and Shapiro-Wilk test showed that it could not be assumed to be normal. The Kruskal-Wallis test proved that there was a group of different sizes, so the post-hoc test was performed using the Mann-Whitney test. The significance level was .008 in inter-group comparisons and .001 in intra-group comparisons by Bonferroni's method.

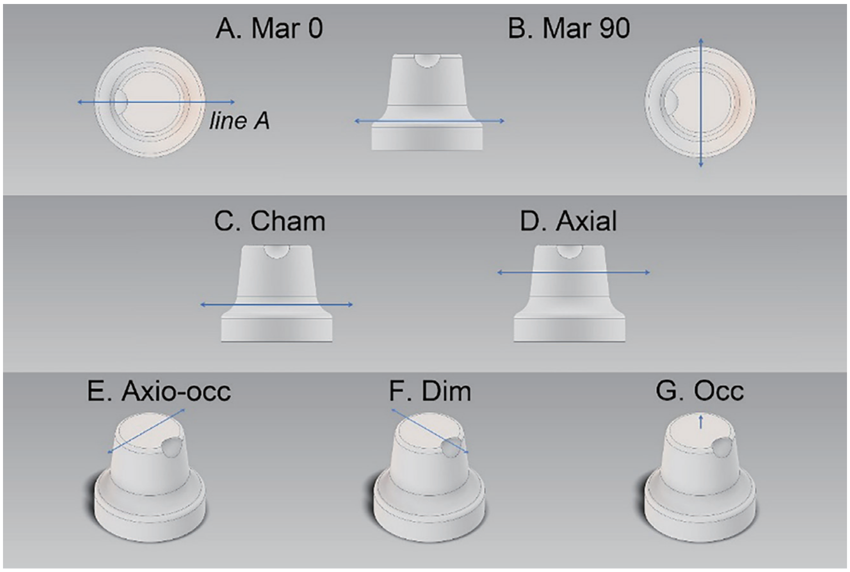


**Fig. 2.** Measuring areas. The parenthesis are the abbreviations. (A) The marginal area at 0° from the dimple (Mar 0), (B) The marginal area at 90° from the dimple (Mar 90), (C) The chamfer area (Cham), (D) The axial area (Axial), (E) The axio-occlusal area (Axio-occ), (F) The anti-rotational area (Dim), (G) The occlusal area (Occ).

## RESULTS

The mean values measured at each part of the crowns in all groups were shown as follows, which were divided into intra- and inter-group comparison (Table 3).

In Group Control, Occ & Dim showed high values and Mar 0 & Mar 90 showed low values comparatively. In Group SZ, Occ & Dim showed the highest values and were not significantly different. Mar 0 showed the lowest value and Mar 90 & Cham were not significantly different. In Group DZ, Occ & Dim showed the highest values and were not significantly different. Mar 0 & Mar 90 & Cham showed the lowest values and were not significantly different. In group DW, Occ & Dim showed high values and Mar 0 & Cham & Axio-occ showed low values comparatively. In all groups, Occ was the largest followed by Dim (Fig. 3).

In Mar 0, group DW showed the highest value and

**Table 3.** Mean value for each area of the specimens in each group

| | Group Control | Group SZ | Group DZ | Group DW |
|---|---|---|---|---|
| Mar 0 (mm) | 0.015 | 0 | 0.003 | 0.047 |
| Mar 90 (mm) | 0.006 | 0.017 | 0.006 | 0.068 |
| Cham (mm) | 0.035 | 0.020 | -0.005 | 0.034 |
| Axial (mm) | -0.023 | -0.023 | -0.030 | -0.049 |
| Axio-occ (mm) | -0.047 | -0.008 | -0.033 | 0.047 |
| Dim (mm) | 0.235 | 0.183 | 0.171 | 0.203 |
| Occ (mm) | 0.281 | 0.189 | 0.174 | 0.317 |
| Compare1 (mm) | 0.035 | 0.025 | 0.009 | 0.043 |
| Volume Cr ($mm^2$) | 128.859 | 128.090 | 124.461 | 128.237 |
| Volume Di ($mm^2$) | 125.275 | 125.353 | 123.605 | 124.291 |
| Surface deviation ($mm^2$) | 3.585 | 2.734 | 0.856 | 3.946 |

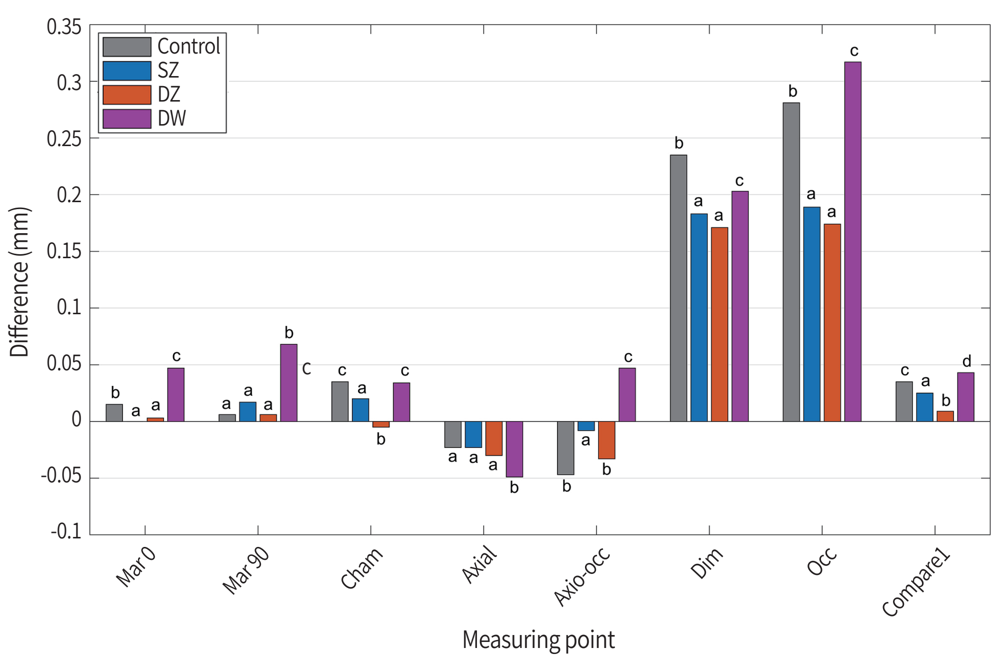


**Fig. 3.** The comparison at each area in each group. The groups marked with different letter showed significant differences at each area ($P < .008$).

group SZ, DZ showed low values. In Mar 90, Axial, group DW showed the highest value. Group Control, SZ, and DZ showed low values and were not significantly different. In Cham, Group Control, DW showed high value and were not significantly different. Group DZ showed the lowest value. In Axio-occ, Group Control, DZ, and DW showed high values and Group SZ showed the lowest value. In Dim, Occ, Group Control, DW showed high value and Group SZ, DZ showed low values comparatively. In Compare1, the values were high in the order of Group DW, Control, SZ, and DZ and were significantly different. In surface deviation, Group Control, SZ, and DW showed high values and Group DZ showed low value comparatively (Fig. 3 and Fig. 4).

## DISCUSSION

In all groups, the center of the occlusal area and the anti-rotational dimple area showed significantly greater difference than other areas. All the 3D printers (SLA, DLP) and the milling machine showed the greatest inaccuracy at the center of the occlusion area and the anti-rotational dimple area. The center of the occlusal area showed greater inaccuracy than the anti-rotational dimple area. We thought that the center of the occlusal area was easier to accumulate errors than other parts because it was the inner most part of the actual crown. We thought that the anti-rotational dimple areas showed greater differences than other parts because they have severe curvature and structural complexity. However, in this experiment, the number of specifications was relatively low and the small number of printers was tested. The results heavily depend on the printers, the materials, their settings, and the overall setting of the experiment. Therefore, it can only be concluded for this specific setup, and no general statement is possible.

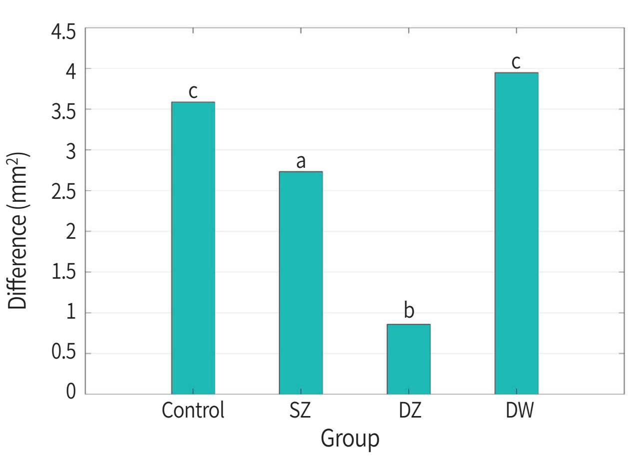


**Fig. 4.** The comparison of surface deviation in each group. The groups marked with different letter showed significant differences ($P < .008$).

In all groups, the marginal area showed the smallest difference comparatively. It is thought that the marginal area is thinner than others, so the shrinkage of polymerization is smaller. It is thought that the marginal area is located relatively to the outer surface, so the errors in the scanning process could have been less.

Compare1, surface deviation were higher in order of group DW > Control > SZ > DZ. The precision of the output is determined by the size of the cutting tools in the CAM method, by the spot size of laser in the SLA method, and by the resolution of x-y in the DLP method. We thought that the milling machine is the most disadvantageous, but it showed better precision than the DLP method. This indicates that neither the subtractive nor the additive method can be said to be superior in the precision.

It was assumed that the SLA method would exhibit higher precision because it polymerizes on a line-by-line basis, while the DLP method magnifies the UV laser transmitted the lens and polymerizes on a surface-by-surface basis. However, group DZ showed significantly higher precision than group SZ. This means that the DLP method exhibits higher precision under the same conditions using the same resin. In this study, it is thought that the size of the crown was small so the pixel distortions at the edges of light occurred less. The SLA method showed the highest precision when the build angle was 120 degrees according to the study by Alharbi *et al*., and the DLP method showed the highest precision when the build angle was 135 degrees according to the study by Osman *et al*..[10,20] The experiment was designed on the basis of the above studies. But the advantage of the SLA method polymerized by the linear unit was not shown in our study because the surface of the output was not perpendicular to the long axis of the actual crown and this could have affected the results. Also, from the clinical point of view, the DLP method, which takes shorter time to print temporary crowns on the same day, is useful than the SLA method. In this study, the DLP method showed higher accuracy than the SLA method under the same conditions. However, more researches are needed for the multi-units as pixel distortion may occur more.

Meanwhile, group DW showed the least precision and group DZ showed the highest precision using the same DLP method. It is thought that the resin used has affected the results because the equipment of group DW showed higher resolution than that of group SZ. Also, because the numbers of specimens were small and the unit of difference was small, the degree of polymerization of the resin would have affected the results. Therefore, the research about the effect of resin polymerization on precision is needed.

## CONCLUSION

Based on the findings of this *in vitro* study, the following conclusions were drawn:

Additive and the subtractive methods show varied accuracies depending on the equipment specifications. The DLP method shows higher accuracy compared to the SLA method when using the same resin material. The DLP method shows different accuracies depending on the equipment and resin material.

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