



# Marginal and internal fit of 3D printed provisional crowns according to build directions

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**PURPOSE.** This study aimed to fabricate provisional crowns at varying build directions using the digital light processing (DLP)-based 3D printing and evaluate the marginal and internal fit of the provisional crowns using the silicone replica technique (SRT). **MATERIALS AND METHODS.** The prepared resin tooth was scanned and a single crown was designed using computer-aided design (CAD) software. Provisional crowns were printed using a DLP-based 3D printer at 6 directions (120°, 135°, 150°, 180°, 210°, 225°) with 10 crowns in each direction. In total, sixty crowns were printed. To measure the marginal and internal fit, a silicone replica was fabricated and the thickness of the silicone impression material was measured using a digital microscope. Sixteen reference points were set and divided into the following 4 groups: marginal gap (MG), cervical gap (CG), axial gap (AG), and occlusal gap (OG). The measurements were statistically analyzed using one-way ANOVA and Dunnett T3.

**RESULTS.** MG, CG, and OG were significantly different by build angle groups ( $P < .05$ ). The MG and CG were significantly larger in the 120° group than in other groups. OG was the smallest in the 150° and 180° and the largest in the 120° and 135° groups. **CONCLUSION.** The marginal and internal fit of the 3D-printed provisional crowns can vary depending on the build angle and the best fit was achieved with build angles of 150° and 180°.

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**KEYWORDS:** Crowns; Printing; Three-dimensional; Dental marginal adaptation; Dental internal fit

## INTRODUCTION

Recently in dentistry, various dental prostheses are being fabricated using an additive manufacturing technique called '3D printing.' Since the technique builds the form by stacking the material layer by layer, it can be used to make more complex forms of prosthesis than using subtractive manufacturing.<sup>1</sup> In addition, the amount of material used can be reduced and details finer than the width of a cutting bur can

be fabricated.<sup>2</sup>

The method of additive manufacturing varies depending on the material employed, among which the digital light processing (DLP) method involves the layering of a liquid photopolymer by light to produce the final form.<sup>3</sup> Compared to the stereolithography (SLA) method, in which each layer is made up of fine lines produced by a laser beam, the DLP method allows faster fabrication time as each layer is created with a single lighting step.<sup>4</sup>

The direct technique of fabricating temporary crowns using polymethyl methacrylate (PMMA) has been frequently used for convenience and low costs of production, but it has the drawbacks of polymerization shrinkage, marginal discrepancy, and heat production.<sup>5</sup> Today, indirect fabrication is possible using computer-aided design/computer-aided manufacturing (CAD/CAM), which facilitates remaking provisional crowns that were lost or fractured during long-term use due to orthodontic treatment or altered vertical dimension.<sup>6</sup> Digholkar *et al.*<sup>7</sup> reported that provisional crowns made by 3D printing show higher microhardness than those made by conventional methods. Furthermore, several studies have reported that using an indirect rather

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than a direct technique to fabricate the provisional crown yields better internal fit.<sup>8</sup>

For 3D printing, a CAD model is stored as a standard tessellation language (STL) file and then placed on the build platform once the build direction has been determined. Cheng *et al.*<sup>9</sup> reported that choosing the right build direction enhances the volumetric accuracy, reduces the time and cost of production, and minimizes the supports needed for printing. In previous studies, provisional crowns were fabricated in only one build direction to evaluate internal and marginal fit.<sup>10,11</sup> Other studies have evaluated the dimensional accuracy of provisional crowns by three-dimensional superimposition method based on various build directions.<sup>12,13</sup> However, few studies have evaluated marginal and internal fit for various build directions.

There are various methods of measuring the marginal and internal fit of a prosthesis, of which the silicone replica technique (SRT), unlike other methods, allows directly fitting of the crown to the tooth intraorally to assess the fit.<sup>14</sup> SRT has also been reported to show no difference from the cross-section method, in which a cross-section is cut from the specimen and directly observed,<sup>15</sup> and has been actively employed in research as a relatively simple method that requires no cutting of prosthesis.<sup>14</sup>

The present study aims to print provisional crowns at varying build directions using a DLP-based 3D printer and evaluate the marginal and internal fit of the printed crowns using SRT. The null hypothesis is that the build directions

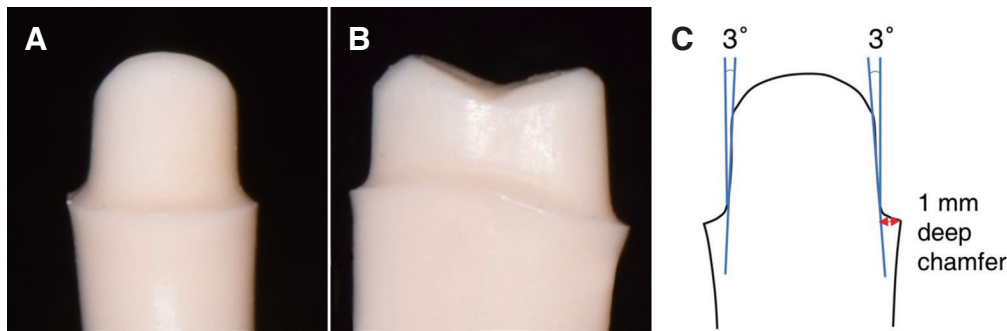
have no effect on the marginal and internal fit of the provisional crowns.

## MATERIALS AND METHODS

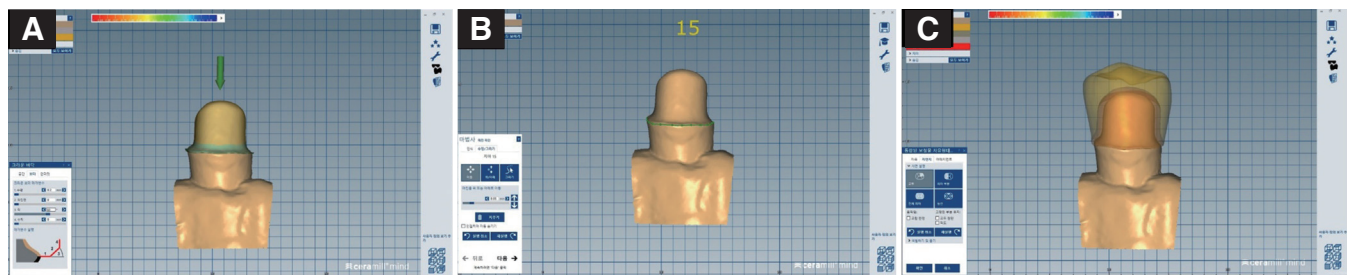
A maxillary second premolar resin tooth (A5AN-500, Nissin Dental Products Inc., Kyoto, Japan) was prepared by reducing 2 mm on the occlusal surface and a total of 6° convergence angle with a 1 mm circumferential deep chamfer finish line (Fig. 1). The prepared resin tooth was then scanned using a model scanner (Ceramill Map 400, Amann Girrbach, Koblach, Austria). After converting the scan data into STL format, a single premolar crown was designed using CAD software (Ceramill Mind, Amann Girrbach, Koblach, Austria). A 30 μm cement gap was set at 1 mm above the finish line (Fig. 2).<sup>16</sup>

The designed crown was exported into a 3D printer software (Flashprint, Flashforge, Jinhua, China). Ten crowns were placed on a platform in the 3D printer software and rotated according to each build direction. The 120° direction was defined as the orientation after positioning the lingual surface of the crown parallel to the build platform and rotating it 30° on the Y-axis. The crown was rotated 15° or 30° in the direction of the Y-axis until the support was placed on the buccal surface. The support was to be automatically positioned only on the surface that formed an angle of ≥ 30° with the Z-axis.

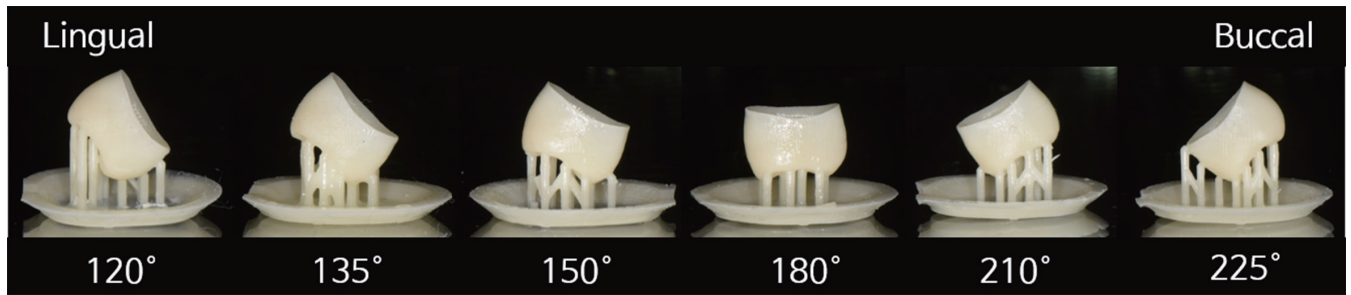
Provisional crowns were printed using a DLP-based 3D



**Fig. 1.** Preparation of maxillary second premolar resin tooth. (A) Buccal view, (B) mesial view, (C) axial reduction of 6-degree convergence angle with circumferential 1 mm deep chamfer finish line.



**Fig. 2.** Designing single crown with CAD software. (A) Virtual cement gap of 30 μm set at 1 mm above finish line, (B) finish line of abutment delicatated, (C) designed crown.



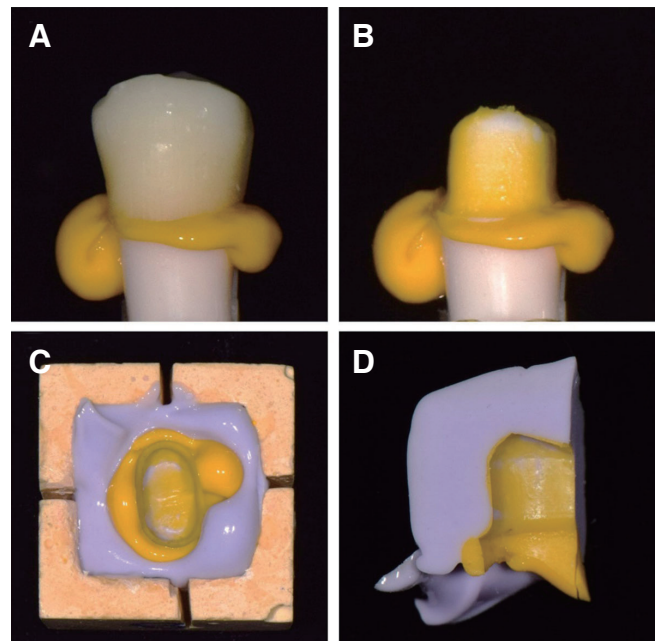
**Fig. 3.** Provisional crowns were printed at 6 build directions (120°, 135°, 150°, 180°, 210°, 225°) using 3D printer.

printer (Hunter, Flashforge Corp., Jinhua, China) at 6 directions (120°, 135°, 150°, 180°, 210°, 225°) with 10 crowns in each direction (Fig. 3). In total, sixty crowns were printed. In each build direction, the crowns were printed using a liquid photopolymer (NextDent C&B, 3D systems, Soesterberg, Netherlands) with the layer thickness set to 50  $\mu\text{m}$ . Complying with the manufacturer's instruction, the prints were washed for 5 minutes using 96% 2-propanol (Merck, Emsure, Darmstadt, Germany) and cured for 45 minutes using light-curing unit (LC-3D Print Box, 3D systems, Soesterberg, Netherlands).

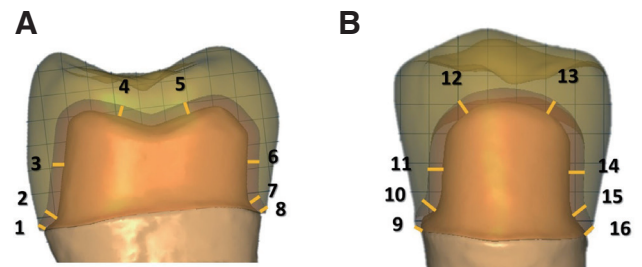
The marginal and internal fit was measured using SRT. Low-viscosity silicone impression material (Honigum light, DMG, Hamburg, Germany) was applied to the inner surface of the crown and fitted to a resin dental model. The crown was pressed until final polymerization was complete and removed after 3 minutes and 30 seconds as instructed by the manufacturer. To cut out the low-viscosity silicone more easily, a silicone interocclusal recording material (Regisil Rigid, Dentsply Sirona, York, PA, USA) was applied around the remaining impression material in the dental model. After removing the fabricated silicone replica from the dental model, it was sectioned evenly in the buccopalatal and mesiodistal direction within the pre-made frame (Fig. 4).

According to the method proposed by Holmes *et al.*,<sup>17</sup> 16 reference points were set and divided into the following 4 groups: marginal gap (MG), cervical gap (CG), axial gap (AG), and occlusal gap (OG). MG was defined as absolute marginal discrepancy.<sup>17</sup> The internal fit was evaluated and divided into CG, AG, and OG. The vertical distance from the deepest of the margin to the inner surface of the crown was measured as CG. In the cross-section, the middle of the axial wall was defined as AG and the middle of the occlusal surface was defined as OG (Fig. 5). Each point was observed at 160 $\times$  using a digital microscope (KH-7700, Hirox, Tokyo, Japan) and the thickness of the low-viscosity silicone was measured at each point.

The measurement results were statistically analyzed with one-way ANOVA using SPSS for Windows (SPSS v20.0, IBM, Chicago, IL, USA). For post-hoc analysis, the Dunnett T3 method was used, since homogeneity was not assumed and the sample size was less than 50. The data was evaluated at a significance level of  $P < .05$ .



**Fig. 4.** Fabrication of silicone replica. (A) Low viscosity silicone impression material was applied to the inner surface of the crown and fitted to resin tooth model, (B) crown was removed and bite registration material was applied on low viscosity silicone, (C) silicone replica was sectioned in buccopalatal and mesiodistal directions, (D) sectioned silicone replica.



**Fig. 5.** Sixteen measuring points for the marginal and internal gap of the crown. (A) Buccopalatal section, (B) Mesiodistal section. Marginal gap (MG): 1, 8, 9, 16; cervical gap (CG): 2, 7, 10, 15; axial gap (AG): 3, 6, 11, 14; occlusal gap (OG): 4, 5, 12, 13.

## RESULTS

The measurement results of the marginal and internal gaps for each direction group are presented in Table 1. The gap in each group is the average of the 4 measuring points (buccal, palatal, mesial, and distal). One-way ANOVA indicated that the build directions have a significant influence on MG, CG, and OG. The post-hoc test was conducted to see if there were any significant differences between build angles in MG, CG, and OG.

MG was significantly larger in the 120° group ( $113.6 \pm 78.3 \mu\text{m}$ ) than in the 150° ( $58.5 \pm 32.3 \mu\text{m}$ ), 180° ( $65.1 \pm 36.0 \mu\text{m}$ ), and 210° ( $69.8 \pm 39.3 \mu\text{m}$ ) groups ( $P < .05$ ). There was no significant difference between the 150°, 180°, and 210° groups ( $P > .05$ ). There was no significant difference from any build angle in the 135° and 225° groups in

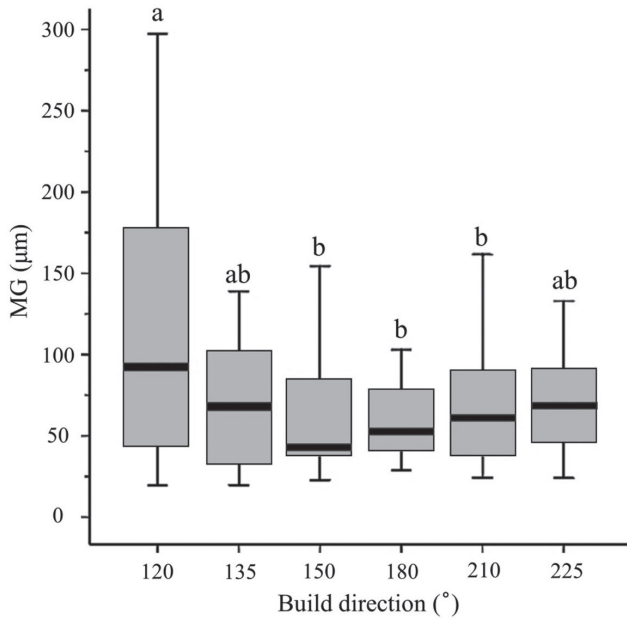
MG ( $P > .05$ ) (Table 1, Fig. 6). CG was significantly larger in the 120° group ( $150.7 \pm 75.6 \mu\text{m}$ ) than in the 150° group ( $101.2 \pm 47.9 \mu\text{m}$ ) ( $P < .05$ ). There was no significant difference between the 135°, 180°, 210°, and 225° groups ( $P > .05$ ) (Table 1, Fig. 7). AG was not significantly different across all the build directions, showing a  $P$ -value of 0.181 ( $P > .05$ ) (Table 1, Fig. 8). OG was the smallest in the 150° ( $75.0 \pm 28.1 \mu\text{m}$ ) and 180° ( $76.1 \pm 16.8 \mu\text{m}$ ) groups, followed by the 210° group ( $105.9 \pm 43.4 \mu\text{m}$ ), while it was the largest in the 120° ( $153.0 \pm 58.1 \mu\text{m}$ ) and 135° ( $142.1 \pm 56.4 \mu\text{m}$ ) groups. In addition, the OG was significantly larger in the 225° group ( $115.3 \pm 60.0 \mu\text{m}$ ) compared to the 150° and 180° groups ( $P < .05$ ). The 225° group showed no significant difference from the 120°, 135°, and 210° group ( $P > .05$ ) (Table 1, Fig. 9).

**Table 1.** One-way ANOVA for marginal and internal gaps in 6 build direction groups

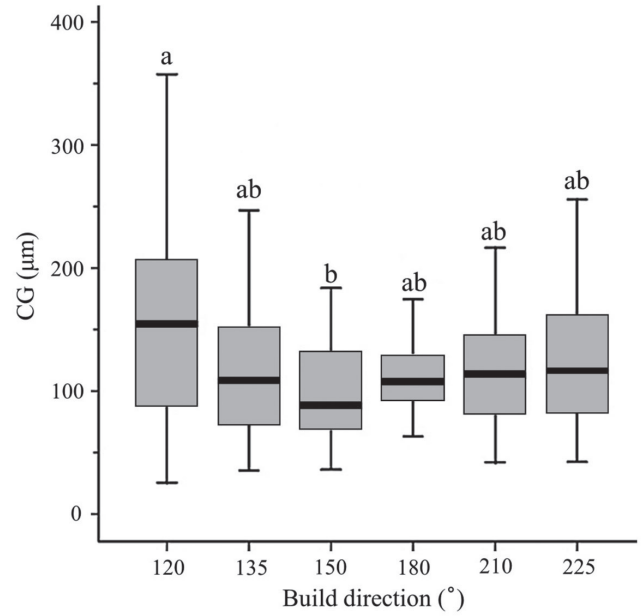
	Group (°)	Mean ( $\mu\text{m}$ )	Standard deviation (SD)	F	$P$ value
MG	120	113.66	78.30	6.467	.000*
	135	73.13	48.48		
	150	58.52	32.32		
	180	65.18	36.04		
	210	69.86	39.32		
	225	75.41	40.45		
CG	120	150.74	75.70	3.914	.002*
	135	116.72	56.30		
	150	101.27	47.96		
	180	113.82	32.49		
	210	118.36	44.64		
	225	125.92	50.99		
AG	120	52.37	28.79	1.532	.181
	135	57.50	32.94		
	150	57.36	31.26		
	180	69.03	32.86		
	210	55.97	23.81		
	225	55.50	24.78		
OG	120	153.00	58.14	19.326	.000*
	135	142.18	56.45		
	150	75.05	28.18		
	180	76.10	16.85		
	210	105.99	43.47		
	225	115.31	60.03		

MG, Marginal gap; CG, Cervical gap; AG, Axial gap; OG, Occlusal gap.

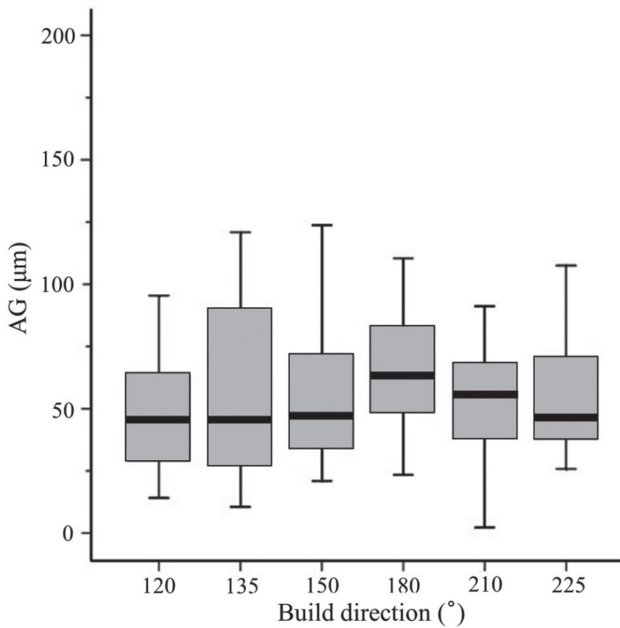
\*Differences significant at  $P < .05$ .



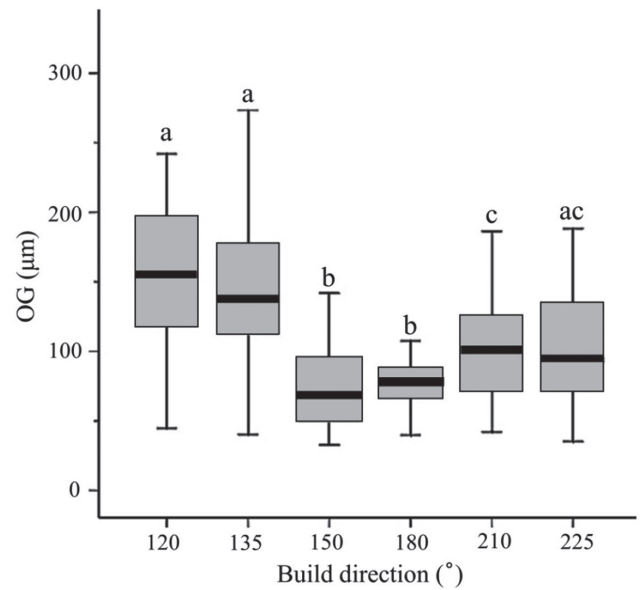
**Fig. 6.** Mean values of marginal gap in six build direction groups. Different letters indicate statistically significant differences among 6 groups ( $P < .05$ ).



**Fig. 7.** Mean values of the cervical gap in six build direction groups. Different letters indicate statistically significant differences among 6 groups ( $P < .05$ ).



**Fig. 8.** Mean values of axial gap in six build direction groups ( $P = .181$ ).



**Fig. 9.** Mean values of occlusal gap in six build direction groups. Different letters indicate statistically significant differences among 6 groups ( $P < .05$ ).

## DISCUSSION

This study was conducted to evaluate the effect of build directions on the marginal and internal fit of the provisional crowns using SRT. As a result, there was a difference in the marginal and internal fit according to build directions. Thus, the null hypothesis was rejected.

In a previous study, Abdullah *et al.*<sup>18</sup> evaluated a MG of provisional crowns made with 4 types of resin using low-viscosity silicone impression material and reported a mean MG of 47 - 193  $\mu\text{m}$ . Yao *et al.*<sup>19</sup> reported a MG of 150 - 280  $\mu\text{m}$ , after fabricating provisional crowns using 4 resin types and attaching using glass ionomer cement. Belser *et al.*<sup>20</sup> asserted that the clinically permissible MG in the final prosthesis was 120  $\mu\text{m}$ , while Beuer *et al.*<sup>21</sup> reported a range of 100 - 150  $\mu\text{m}$ . In the present study, the MG was shown to be 58 - 113  $\mu\text{m}$ , which falls within the clinically permissible range.

Internal fit affects the retention and resistance of the crown,<sup>22</sup> in which OG is often the largest measured gap than CG or AG.<sup>23</sup> According to Boitelle *et al.*,<sup>24</sup> the internal fit of CAD/CAM prostheses made with various materials was 45 - 219  $\mu\text{m}$  in the OG. Alharbi *et al.*<sup>11</sup> reported an incisal gap of 169  $\mu\text{m}$  in the 3D-printed anterior provisional crown, which was 1.5 times greater than the assigned cement gap. Kokubo *et al.*<sup>25</sup> reported an incisal gap of 170  $\mu\text{m}$ , which was 3 - 4 times greater than the cement gap. In this study, the cement gap was set to be 30  $\mu\text{m}$  and the measured OG was 75 - 152  $\mu\text{m}$ , which was 2.5 - 5 times greater. The AG shows a different pattern. Alharbi *et al.*<sup>11</sup> reported an AG of 41  $\mu\text{m}$ , which is smaller than the defined cement gap of 60  $\mu\text{m}$ . In this study, the AG was 52 - 69  $\mu\text{m}$ , which was smaller than OG and CG. This was due to the errors in STL file splitting, thus it is necessary to increase the cement gap in the axial wall to enhance the fit.<sup>11</sup>

Park *et al.*<sup>26</sup> studied 3D-printed 3-unit fixed partial dentures using resin in 5 build angles (0°, 30°, 45°, 60°, 90°) and found a significant difference in the marginal and internal fit, in which the optimal build angles were 45° and 60°, corresponding to 135° and 120° in our study. Alharbi *et al.*<sup>12</sup> compared the three-dimensional accuracy of resin crowns 3D-printed at 9 different angles using superimposition software and concluded that the optimal build angle was 120°, considering the position of support and time needed for finishing and polishing. In addition, Osman *et al.*<sup>13</sup> compared the three-dimensional accuracy of DLP-printed resin crowns and reported 135° as the optimal angle. In this study, MG and CG were significantly larger in the 120° group than in other groups, while OG was the smallest in the 150° and 180° and the largest in the 120° and 135° groups. Therefore, considering the marginal and internal fit, 150° and 180° are recommended as the optimal build angles.

There are various reasons for the differences in the marginal and internal fit based on the build angle. First, the form of the layer created by the 3D printer differs according to the build angle. Since a DLP-based 3D printer polymerizes one layer at a time, any change in the layer form

entails changes in the form and degree of polymerization shrinkage.<sup>27,28</sup> For example, in the case of a hollow cylindrical object, there is a part that is consistently exposed to light, which affects the internal fit.<sup>15</sup> Moreover, the position of support attachment changes with the build angle. Errors can arise from the unsupported section. If support is attached close to the crown margin, then unwanted damage can be incurred during the removal of the support.<sup>12</sup> Although supports were attached symmetrically in the 150° and 210° groups, OG was significantly larger in the 210° group whose support was located more buccally. The number of supports was 13 in the 150° group and 11 in the 210° group, which explains the error in the 210° group by its relatively fewer supports.

Osman *et al.*<sup>13</sup> fabricated and scanned provisional crowns in 9 different angles using a DLP-based method and obtained a color map by superimposing with original data, which showed a positive change in the internal surfaces of the supported area and the opposite area when build angles of 90°, and 270° were used. This can be explained by the gravitational effects on the liquid medium as the platform moves up and down during printing. In the preliminary experiments of this study, 90°, 240°, and 270° were excluded from the experimental group for imperfect fit, which can be explained by the same reason. Furthermore, AG was smaller in the 120° group than in other groups, while OG and CG were larger, suggesting that fit was imperfect in the axial plane.

Attempts have been made in many studies to reduce the area of support by changing the build angle.<sup>4,29-31</sup> Attaching support to the object increases the printing time and the amount of material used, while removing the support requires a considerable amount of manual work and time and can degrade surface quality.<sup>32</sup> Here, the build angle is selected manually, semi-automatically or automatically. In the manual mode, the user can directly set the build angle on the platform. In the semi-automatic mode, the angle is determined based on the feedback information on printing time and support area. In the automatic mode, it is determined by a specific algorithm that takes the printing time, as well as the amount and area of support into account.<sup>33</sup> Previous studies have proposed various algorithms to find the optimal build angle.<sup>34,35</sup> The differences in fit after applying various algorithms must be further studied.

In this study, when the provisional crowns were printed at an build direction of 120° to 225° using a DLP 3D printer, the optimal build angles were 150° and 180°. However, the limitation is that the cement thickness to which the crown was suitable at all angles was not set. As a result, the difference in the fit according to the position of the support was not comparable in all build angles. Also, further studies are needed to evaluate the influence of various parameters such as layer thickness, support type and location on the platform that should be considered during crown printing.

## CONCLUSION

When provisional crowns were fabricated using a DLP-

based 3D printer within the limits of this study, the marginal fit was shown to be clinically permissible across all build angles. The internal fit was shown to be different in the cervical and occlusal surfaces depending on the build angle. Considering the marginal and internal fit, 150° and 180° are recommended as the optimal build angles.

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