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Effect of rinsing time on the accuracy of interim crowns fabricated by digital light processing: An *in vitro* study

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PURPOSE. This study was to evaluate the effect of rinsing time on the accuracy of interim crowns fabricated by digital light processing. **MATERIALS AND METHODS.** The maxillary right first molar master die was duplicated using a silicone material, while a study die was produced using epoxy resin. Scans of the epoxy resin die were used in combination with CAD software to design a maxillary right first molar interim crown. Based on this design, 24 interim crowns were fabricated with digital light processing. This study examined the trueness and precision of products that were processed with one of the three different post-processing rinsing times (1 min, 5 min, and 10 min). Trueness was measured by superimposing reference data with scanned data from external, intaglio, and marginal surfaces. Precision was measured by superimposing the scan data within the group. The trueness and precision data were analyzed using Kruskal-Wallis, nonparametric, and post-hoc tests, and were compared using a Mann-Whitney U test with Bonferroni correction (α=.05). **RESULTS.** The trueness of the external and intaglio surfaces of crowns varied significantly among the different rinsing times (*P*=.004, *P*=.003), but there was no statistically significant difference in terms of trueness measurements of the marginal surfaces (*P*=.605). In terms of precision, statistically significant differences were found among the external, intaglio, and marginal surfaces (*P*=.001). **CONCLUSION.** Interim crowns rinsed for 10 minutes showed high accuracy. [J Adv Prosthodont 2021;13:24-35]

KEYWORDS
Additive manufacturing; Digital light processing; Rinsing time; Interim crown; Accuracy

INTRODUCTION

Interim restorations, which accurately reflect the requirements of individual patients, are essential for the successful fabrication of fixed dental prostho-

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dontics. Interim restorations are the first step in the creation of fixed dental prosthodontics and serve not only to prevent tooth movement and maintain space but also to protect pulp and periodontal tissues of abutments.[1,2] In addition, through an interim restoration step, errors of definitive restorations for esthetics, occlusion, and pronunciation recovery can be minimized.[3,4]

Traditional methods of producing an interim restoration can lead to increased errors due to polymer shrinkage of the resin, which decreases the accuracy of the final prosthesis. In addition, labor-intensive and long manufacturing processes depend on the skills of the dental technician and can increase the possibility of errors while decreasing the accuracy of interim crowns.[5,6] Dental computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been used to improve the accuracy of interim crowns.[7,8] These systems can simplify existing manufacturing methods, thereby reducing labor intensity and eliminating the possibility of biological allergies caused by auto-polymerized resins.[5-8]

Dental CAD/CAM systems are classified according to their processing methods into subtractive manufacturing and additive manufacturing.[9,10] Vat polymerization 3D-printing, which uses a photopolymer that is selectively cured, is a commonly used additive manufacturing method in the dental field. Stereolithography apparatus (SLA) and digital light processing (DLP) are two types of vat polymerization 3D-printing.[9-12] The SLA method can produce a high-resolution object using a laser or ultraviolet (UV) light source, but it requires a large investment in terms of time since the product is produced one layer at a time.[13-15] The DLP method uses a UV project light source emitted from an arc lamp or a digital micro mirror device such that one layer is produced each time the light beam is transmitted.[16-19] Because DLP is faster than SLA, researchers have been interested in the utility of this method for the manufacturing of dental casts, castable resins, and interim crowns.[15] In contrast to subtractive manufacturing, where products are constructed by the removal of material, vat polymerization 3D-printing can reproduce the undercut portion of teeth and produce high-resolution, complicated products while using minimal materials.[7,9,11-15]

There are several processes in vat polymerization 3D printing manufacturing processes such as SLA and DLP. In general, the vat polymerization 3D printer's manufacturing stage is divided into pre-processing and post-processing stages. The pre-processing step is performed before the vat polymerization 3D printer is operated, with layer thickness setting, support formation, and printing direction setting of the virtually designed dental restoration as well as the number of arrangements made at this time.[9,13] The post-processing step is executed after processing of the vat polymerization 3d printer is finished, where a rinsing process for removing residual resin and a post curing process for final polymerization of unpolymerized resin between layers is done. Vat polymerization 3D-printing methods such as SLA and DLP require post-processing steps to achieve final polymerization.[9,13-15] These steps can affect the accuracy of the interim prosthesis.[9,15]

Various studies on pre-treatment using the vat polymerization 3D printer have been published. Osman *et al*.[16] evaluated the accuracy of interim crowns produced by the DLP method according to their angles. Alharbi *et al*.[17] also compared the accuracy of interim crowns according to their support thicknesses and build angles. Kim *et al*.[11] evaluated the effect of the number of resin copings on the build platform of a stereolithography apparatus 3D printer. Finally, Park *et al*.[18] evaluated the printing parameters of implant interim restoration produced by the DLP method.

In the case of post-processing, the previous studies on dental restoration produced by the vat polymerization 3D printer method have been conducted only in post-curing steps. Karalekas and Aggelopoulos[19] investigated the shrinkage of post-cured vat polymerization 3D printer resins under heat and UV light sources. Katheng *et al*.[20] evaluated the degrees of polymerization and accuracies of fixed partial restorations made at different temperatures and post-cure times. Kim *et al*.[21] evaluated the dimensional accuracy and adaptation according to the post curing method of an interim full arch fixed restoration manufactured by SLA 3D printer. Rinsing of the additive manufactured product is always the first step in any post-processing process and involves the removal of excess resin using an ultrasonic cleaner within a ded-

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icated solution.[9,10,13-15,22] The degree of residual resin removal in the rinsing process can affect the accuracy of the additive manufactured object.

Previous accuracy evaluation was performed linearly using digital calipers, and recent advances in dental scanners and 3D superimposition software have made it possible to measure accuracies of a wide variety of surfaces.[5,16,17,22-28] Accuracy is classified into trueness and precision. Trueness refers to the degree of agreement between the virtually designed dental restoration and the specimen, while precision indicates the degree of agreement within the specimens.[29]

However, at present, there are no studies evaluating the accuracy of interim restoration according to degrees of rinsing time using the DLP method based on photopolymerization 3D-printing. The purpose of this study was to measure how rinsing time changed the trueness and precision of interim crowns produced with the DLP method. The study's overall null hypothesis was that there are no significant differences among varying rinsing times in terms of trueness or precision of DLP-produced interim crowns.

MATERIALS AND METHODS

The overall protocol flow chart for this study is shown in Figure 1. This study used a maxillary master model (AG-3, Frassaco, Tettnang, Germany) and maxillary right first molar (ANA-3 ZPVK 16, Frasaco, Tettnang, Germany) for the preparation of abutments. The abutment was prepared by removing an occlusal height of 1.5 mm, an axial wall of 1.5 mm, and a 1 mm deep chamber on the margin. An abutment die was duplicated using a silicon material (Deguform, DeguDent, Hanau, Germany) to produce an epoxy die mold. Replicated molds were made using epoxy resin (Polyurock, Metalor Dental, Stuttgart, Germany).

The duplicated epoxy die was scanned with a dental laboratory scanner (Identica Hybrid, Medit, Seoul, South Korea) to fabricate a virtual study die,[24] and the scanned images were saved in Standard Triangulated Language (STL) file formats to create a virtual study die. The blue light LED-based scanner used in this study has high accuracy in scanning impressions and abutments, and is widely used to analyze accuracy.[24] Skilled dental technicians used CAD (Dent CAD,

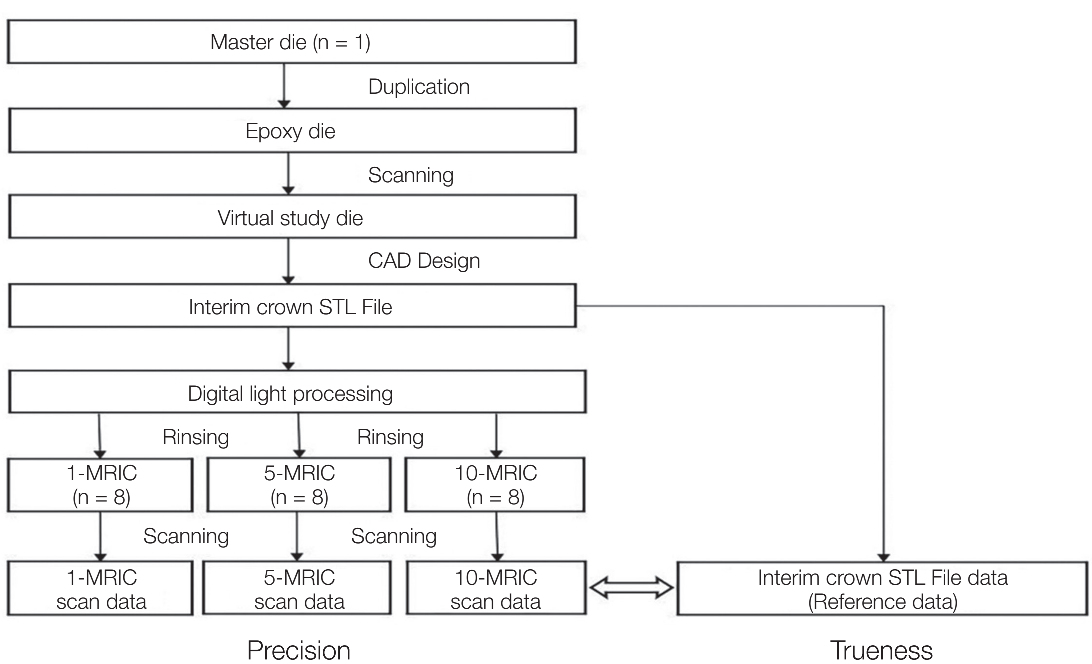

Fig. 1. Flowchart of research protocol.
1-MRIC, 1-Min Rinsing Interim Crown; 5-MRIC, 5-Min Rinsing Interim Crown; 10-MRIC, 10-Min Rinsing Interim Crown.

Delcam PLC, Birmingham, UK) to design the interim crown and reference crown based on the STL files.

After uploading the designed interim crown STL file to the 3D printer program (FlashDLPrint, Flashforge, CA, USA), the build angle of the designed interim crown on the build platform of the program was set to a 45-degree angle.[16] After arranging three virtual interim crowns, a support was created on the external surface.[11] During this time, a support with a thin thickness was used, with the layer thickness being 100 µm for both input and output.[17,18,30]

Resin liquid (NextDent C&B MFH, NextDent, Soesterberg, Netherlands) for the interim crowns was mixed to uniformity for 1 hour using a dedicated stirring device (LC-3D Mixer, NextDent, Soesterberg, Netherlands).[31] After mixing, 24 interim crowns were produced by pouring the resin liquid into the resin tank of the 3D printer along with the additive and manufactured with a digital light processing (DLP) printer (Nextdent 5100, NextDent, Soesterberg, Netherlands). According to the manufacturer's instructions, the accuracy of the DLP 3D printer used in this study was ± 57 µm, and interim crowns were fabricated using a 405 nm wavelength light source.[23]

After manufacturing the interim crowns with DLP, each interim crown was rinsed with 95 % isopropyl alcohol (IPA) using an ultrasonic cleaner for either 1 min (1-Min Rinsing Interim Crown, 1-MRIC), 5 min (5-Min Rinsing Interim Crown, 5-MRIC), or 10 min (10-Min Rinsing Interim Crown, 10-MRIC). After rinsing, all interim crowns were post-polymerized for 15 min at 60°C using an ultraviolet polymerizer (LC-3DPrint Box, NextDent, Soesterberg, Netherlands).[20] The post-polymerized interim crowns were then polished after removal of the support attached to the external surface.

A scan spray (Easy scan, Alpha Dent, Goyang, South Korea) was applied on the intaglio and external surfaces of the printed interim crowns, to prevent errors due to light reflection when collecting scan data. Next, the external, intaglio, and marginal surfaces were scanned using a blue light scanner (Identica Hybrid, Medit, Seoul, South Korea) with an error of 10 µm or less, and the data were saved in STL file format.[24]

The trueness and precision of the external, intaglio, and marginal surfaces were measured by modifying and deleting unnecessary parts using a three-dimensional overlay program (Geomagic Verify 2015, 3D systems, Morrisville, NC, USA). In this study, the overall overlapping process of the external, intaglio, and marginal surface measured interim crown accuracy was shown in Figure 2. Trueness was calculated by overlapping the reference crown and scan data obtained from the 1-MRIC, 5-MRIC, and 10-MRIC groups using the best fit alignment method, while precision was calculated by overlapping the scan data in 1-MRIC, 5-MRIC, and 10-MRIC groups using the combination formula (8C2 = 28). This study evaluated the accuracy at each rinsing time using the root mean square (RMS) equation:

$$\sqrt{\frac{\sum_{k=1}^{n}\left(x_{1,k}-x_{2,k}\right)^2}{n}}$$

where $x_{1,k}$ are the reference data of the interim crown, $x_{2,k}$ are the scan data of the interim crown, and n is the total number of measuring points.[25]

For the intaglio optical deviation analysis, the nominal deviation of the intaglio surface and marginal area was set to ± 50 µm and the critical deviation to ± 100 µm. For the optical deviation analysis of the outer surface, optical deviation was examined by setting the nominal deviation of the external surface to ± 50 µm and the critical deviation to ± 150 µm. Based on the accuracy (± 57 µm) of the DLP 3D printer used in this study and 45 µm of the thickness of the American Dental Association (A.D.A) No. 8 for zinc phosphate cement, the range of the nominal deviation was set at ± 50 µm.[25,32] In addition, in the case of critical deviation, it was set based on previous studies that evaluated the accuracy of the interim crown.[5] This study used the RMS and optical deviation map of trueness and precision to analyze quantitative and optical deviation data.

Statistical software was used to analyze the calculated data (IBM SPSS statistics v24.0, IBM SPSS Inc., Armonk, NY, USA). Type I error level was set to 0.05 for all analyses. Kolmogorov-Smirnov tests showed that the trueness and precision data were not normally distributed. Therefore, a nonparametric statistical method, specifically a Kruskal-Wallis test, was used to test for significant differences among groups. Mann-Whitney U tests with Bonferroni correction (P = .017) were used for post-hoc analyses.

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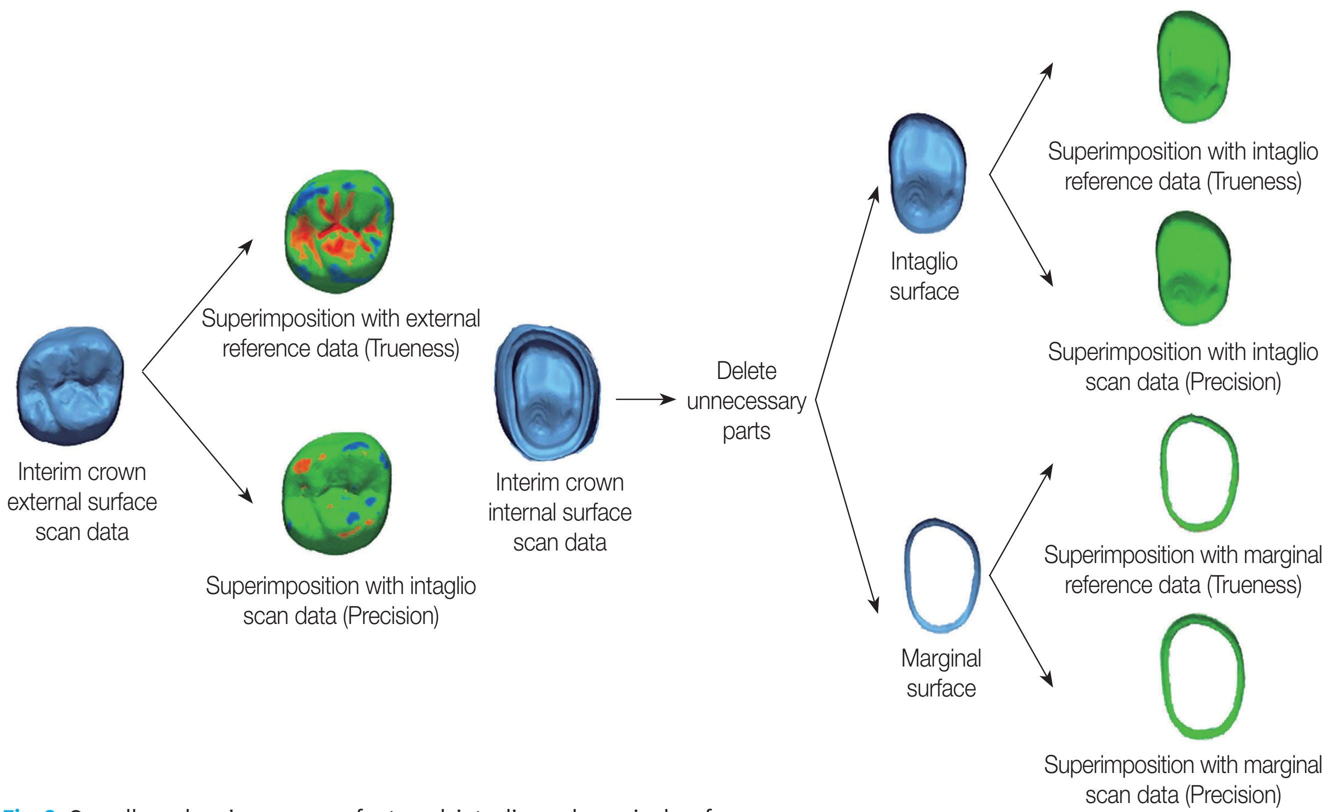

Fig. 2. Overall overlapping process of external, intaglio, and marginal surfaces.

RESULTS

The mean measures of trueness and precision differed among groups (Table 1 and Table 2). Trueness analysis for the quantitative analysis of the fabricated interim crown showed statistically significant differences on the external surface and the intaglio surface, but no statistically significant difference on the marginal surface (Table 1). However, all three measures of precision (external, intaglio, and marginal surfaces) were significantly different among groups (Table 2).

This study examined permissible ranges and errors in a three-dimensional optical deviation map of the optical analysis for both trueness and precision for each group (Fig. 3, Fig. 4, Fig. 5). In terms of trueness, the external surfaces group showed complex deviations (Fig. 3A). The buccal, lingual, mesial, and distal surfaces all showed negative deviation colors, with these deviations being lower in the 10-MRIC group (Fig. 3A). The intaglio surface showed positive deviations in the axial and occlusal areas in the 1-MRIC and 5-MRIC groups but these deviations were within the acceptable range in the 10-MRIC group (Fig. 4A). In the marginal surface, there were partial positive and negative deviations in all groups (Fig. 5A). The study found that deviations in precision were generally within acceptable ranges for all groups, but the occlusal surface of the external surface on which the support had run showed slightly positive and negative deviations (Fig. 3B). Partially positive and negative deviations in the intaglio and marginal surfaces for the 1-MRIC and 5-MRIC groups were also observed, but those same measures were within the acceptable range for the 10-MRIC group (Fig. 4B and Fig. 5B).

DISCUSSION

This study examined how post-production rinsing time affected the accuracy of interim crowns fabricated by DLP. In general, the rinsing time depends on

Table 1. Trueness root mean square (RMS) values of external, intaglio, and marginal surfaces according to rinsing time (unit: µm) (Mean ± SD)

Trueness	1-MRIC	5-MRIC	10-MRIC	*P**
External	62.66 ± 3.07[a]	62.23 ± 4.53[a]	55.71 ± 3.74[b]	.004
Intaglio	24.91 ± 3.62[a]	21.19 ± 1.17[ab]	19.96 ± 1.35[b]	.003
Marginal	129.64 ± 19.35	132.24 ± 12.08	125.88 ± 14.61	.605

1-MRIC, 1-min rinsing of the interim crown; 5-MRIC, 5-min rinsing of the interim crown; 10-MRIC, 10-min rinsing of the interim crown; SD, standard deviation
[a,b] Different superscripts indicate the statistical significance by the Mann-Whitney U-test with Bonferroni correction.
*Analyzed by Kruskal-Wallis test (α = .05).

Table 2. Precision root mean square (RMS) values of external, intaglio, and marginal surfaces according to rinsing time (unit: µm) (Mean ± SD)

Precision	1-MRIC	5-MRIC	10-MRIC	*P**
External	30.76 ± 1.76[a]	34.58 ± 2.79[b]	27.05 ± 2.13[c]	.001
Intaglio	19.37 ± 2.46[a]	19.03 ± 2.56[a]	12.58 ± 1.59[b]	.001
Marginal	36.23 ± 7.51[a]	35.50 ± 4.52[a]	19.28 ± 3.41[b]	.001

1-MRIC, 1-min rinsing of the interim crown; 5-MRIC, 5-min rinsing of the interim crown; 10-MRIC, 10- min rinsing of the interim crown; SD, standard deviation
[a,b,c] Different superscripts indicate statistical significance by the Mann-Whitney U-test with Bonferroni correction.
*Analyzed by Kruskal-Wallis test (α = .05).

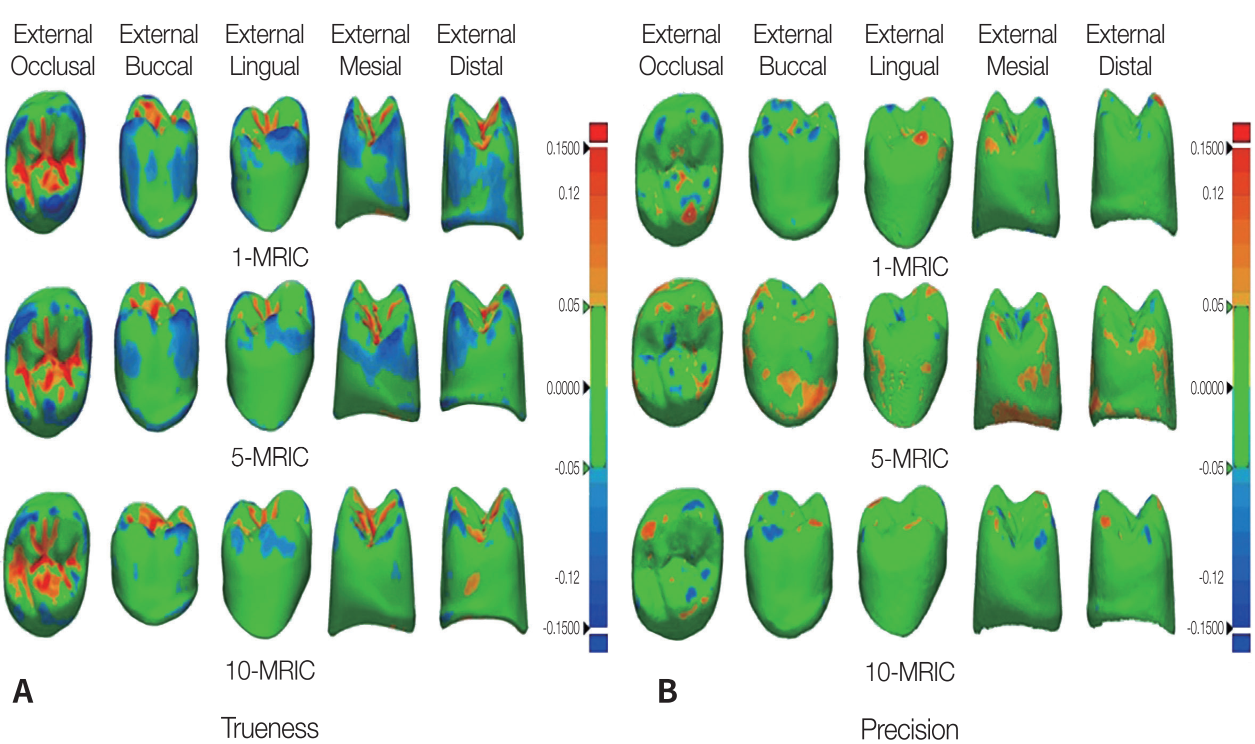

Fig. 3. Optical deviation analysis of external surface using color deviation map. (A) trueness; (B) precision. Green area represents good fit, yellow or red area represent positive error, blue area represents negative error.

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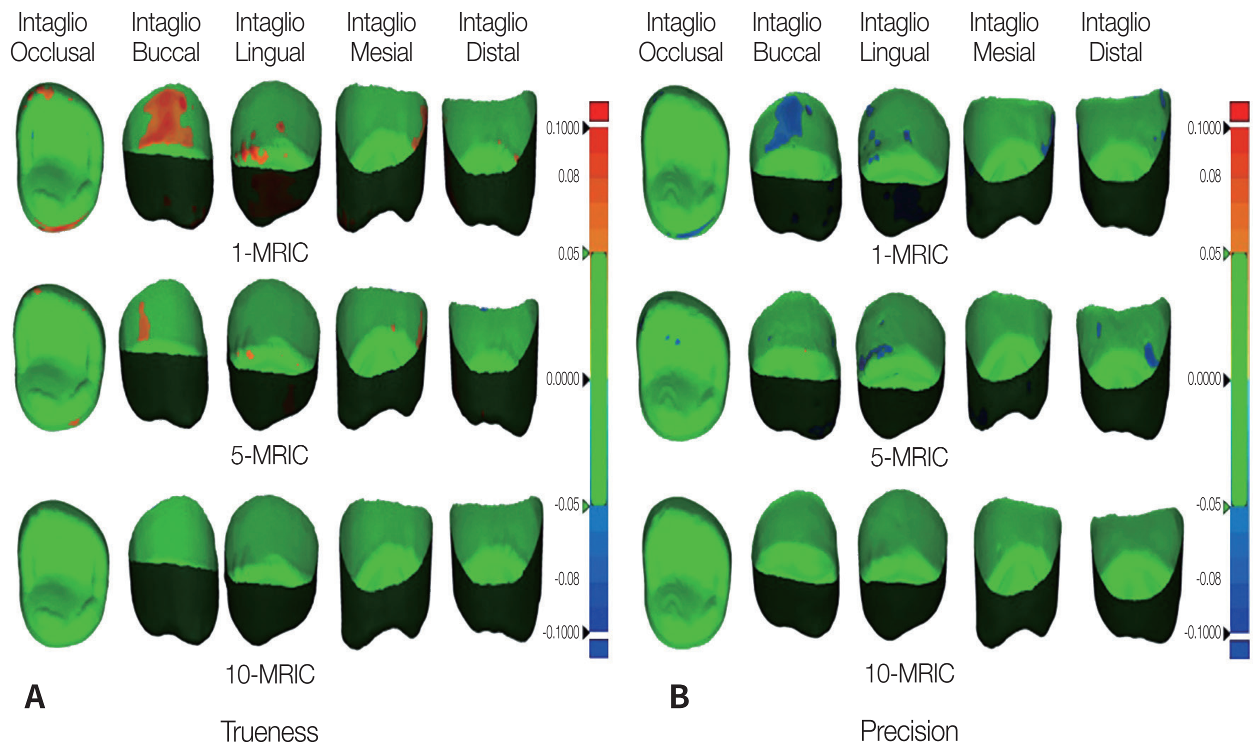

Fig. 4. Optical deviation analysis of intaglio surface using color deviation map. (A) trueness; (B) precision. Green area represents good fit, yellow or red area represent positive error, blue area represents negative error.

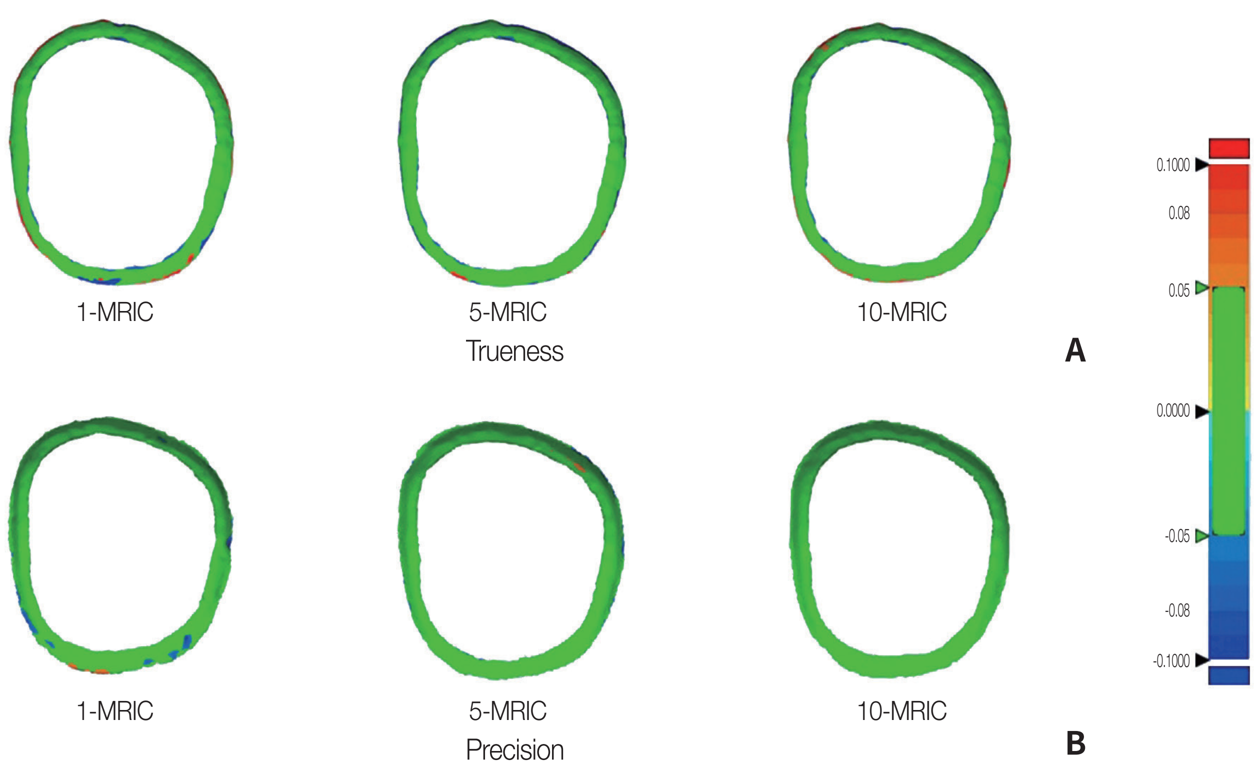

Fig. 5. Optical deviation analysis of marginal surface using color deviation map. (A) trueness; (B) precision. Green area represents good fit, yellow or red area represent positive error, blue area represents negative error.

the 3D printed material, and the range is from 1 to 10 minutes.[16-18,22,23] In this study, in order to systematically standardize the rinsing time, the accuracy was evaluated in 3 groups (1, 5, 10 min) starting with a 1 minute rinsing time and increasing as a multiple of 5 minutes.

In order to minimize errors in the pre-treatment process for this study, interim crowns were fabricated by creating a layer thickness of 100 µm and a build angle of 45-degrees while using a thin support.[16-18,30] Regarding layer thickness, if the dental prosthesis is processed to 50 µm, the resolution and accuracy may increase, but as the manufacturing time increases, the deformation caused by the amount of potential variation in the z-axis may affect the accuracy measurement.[30] In addition, in a previous study, the accuracy of the dental prosthesis in 50 µm and 100 µm layer thickness was within the allowable deviation, so in this study, the interim crown was fabricated with the layer thickness set to 100 µm.[33] In addition, in order to reproduce stable 3D printing, a total of 24 interim crowns were produced by arranging three in one build platform.[11] Also, this study examined accuracy by analyzing trueness and precision using a three-dimensional superposition program that visualized errors appearing on various surfaces, with scan data calculated using a blue light scanner.[24,26-29,34]

After performing the aforementioned method, trueness analysis of the interim crowns produced according to rinsing time (1, 5, and 10 min) using the DLP method was significantly different on the external and intaglio surfaces. Thus, the null hypothesis was initially rejected but was subsequently reconsidered after finding no statistically significant difference on the marginal surfaces (Table 1). However, because there were statistically significant differences in the external, intaglio, and marginal surfaces after precision analysis (Table 2), the null hypothesis was definitively rejected.

The common errors observed in the trueness analysis (Fig. 3A, 4A, and 5A) are best explained by the stair-step effect that can occur during DLP manufacturing. The groove or line angle existing in the occlusal surface and the curved part existing in buccal and lingual surfaces can adversely affect the trueness and decrease the accuracy of the output object.[26,35] In this study, the mean trueness of the external and intaglio surfaces for 10-MRIC was smaller than those of 1-MRIC and 5-MRIC. In contrast, the mean trueness of the marginal surface was larger for 10-MRIC than those of 1-MRIC and 5-MRIC (Table 1).

The study found negative deviations in the buccal and lingual surfaces of all three groups due to the asymmetric contraction of the inner and outer surfaces wherein the curve is large (Fig. 3A). Additionally, this observation was classified as an error due to centripetal shrinkage.[36] Negative deviations were also observed after optical deviation analysis of the mesial and distal portions of the external surfaces. This observation could also be due to errors caused by shrinking in the mesial-distal direction due to the slicing process of the photopolymerized resin layer by layer as well as due to post-processing.[5,7,37]

In this study, the irregular deviations observed on the occlusal surface could be explained by the inability of the rinsing to wash away the residual resin present in the occlusal surface grooves. There is also the possibility of errors occurring due to the direction used for slicing the layers. The layer grains are arranged vertically with respect to the occlusal surface where the cusp tip and the ridge exist.[38] Intaglio surfaces showed partial deviations in the 1-MRIC and 5-MRIC groups (Fig. 4A). This is because after the DLP layer-by-layer manufacturing process is completed, the unpolymerized resin is present on the intaglio surface, which presents as an error while polymerization completes on the build platform. The error on the intaglio surface observed in this study could have been due by the final shape obtained while separating the non-interim crown.[22]

The study observed partial positive and negative deviations on the marginal surfaces (Fig. 5A). These are considered errors when scanning sharp edges such as marginal surfaces.[26,39] A study by Kirsch *et al*.[39] suggested that the analysis of optical deviation is limited by some rounding effect when scanning a sharp spot. The results of the irregular optical deviation analysis of these marginal surfaces are consistent with those of Wang *et al*.[26] and Bae *et al*.[40] There was no significant difference among the 3 groups in terms of quantitative analysis of the marginal surfaces, but the 10-MRIC group showed close to the clini-

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cally acceptable value of 120 μm.[41] The quantitative numerical range of trueness is also consistent with the results of studies by Peng *et al*.[3] and Park *et al*.[42] In addition, the marginal surface is adjacent to the intaglio surface, and dimensional errors may occur due to the light scattering characteristics and deflection during additive manufacturing.[16,17,23,30,43] These factors appear to have influenced the qualitative and optical deviation analysis of marginal surface trueness.

The study found significant differences among rinsing time in terms of precision for all surfaces of the crowns (Table 2). The mean measures of precision for the external, intaglio, and marginal surfaces were lower for 10-MRIC than those of 5-MRIC and 1-MRIC. There was observed partial negative deviations in the intaglio and marginal surfaces for 1-MRIC and 5-MRIC, whereas those measures for 10-MRIC were within acceptable deviations (Fig. 4B and Fig. 5B). These results may reflect an inability to clean the unpolymerized resin on the intaglio surface during rinsing. On the external surface, 1-MRIC, 5-MRIC, and 10-MRIC all showed partial positive and negative deviations in their occlusal surfaces (Fig. 3B). In addition, the observed positive and negative deviations in the area where the support was formed may be errors caused by the removal of the surface on which the support was run from the external surface.[5,30] The present study's results regarding precision of the external surfaces are consistent with the findings of Kang *et al*.[5] and You *et al*.[30]

The results of this study clearly indicate that a 10-min post-processing rinse optimized the accuracy of the external, intaglio, and marginal surfaces of interim crowns produced with DLP. The effects of rinsing time on accuracy differed among crown surfaces. The accuracies of the intaglio and marginal surfaces are more important than that of the external surface since the external surface is corrected by performing bite adjustment and grinding at the support.[30] However, in the case of marginal surfaces, there was no significant difference in terms of trueness value due to slight round effects on each sharp point. Nevertheless, the accuracy results of external and intaglio surfaces, as well as the results of trueness and precision in the 10-MRIC group of marginal surfaces, were lower than those of the other two groups, with the optical deviation map being within 10 min of tolerance. In addition, in this study, postcuring was performed in the same manner in all three groups, and there were factors that influenced the accuracy analysis (stair step effect, centripetal shrinkage, shrinking in the mesial-distal direction, support removal error),[5,7,20,22,26,35-37] but quantitative and optical deviation was showed the different result. Therefore, the existence of such a minor difference means that the rinsing time has an influence on the accuracy of the interim crown, and the results of this study are expected to be used as reference data in manufacturing the interim crown by the DLP method.

There were some limitations to this study, such as its focus is only on interim crowns and lacking consideration of other cleaning devices. Another limitation of the study was that various rinsing methods were not employed. Many studies rinsed the IPA solution without replacement,[3,5,11,12,16-20,23,30,31,36,37] but in the study of Kalberer *et al*.,[22] IPA was first rinsed for 2 min, replaced with a new IPA, and then rinsed again for another 3 min. Therefore, it is crucial that future studies investigate the effects of cleaning time using various cleaning devices and trial dentures, partial fixed dental prostheses, dental casts, and castable resin patterns produced by DLP. In addition, studies should be conducted to compare and evaluate different rinsing methods. In this regard, since rinsing a dental prosthesis for more than 10 minutes may have a different effect on the accuracy,[20,22] future researchers will need to evaluate the accuracy including the group that has been rinsed for 10 minutes or more.

Various dental scanner accuracy and spray powder coated irregularly when applying scan spray can affect accuracy analysis.[24,25,34,44] In the future research, the accuracy analysis of interim crowns manufactured with different rinsing times should be performed with various scanners and with the presence or absence of scan sprays. Additionally, the adaptation of the abutment may also be affected by rinsing time because irregular trueness deviations errors occurred in all three groups in the intaglio and marginal surfaces.[30,45] Future studies should include a comparison of how rinsing time affects the intaglio and marginal surface adaptations of interim crowns. Furthermore, since interim restoration must be stable in the oral environment, additional clinical studies to reproduce and evaluate the situation in the oral environment must be employed in future researches.

CONCLUSION

The results of this *in vitro* study investigating the effects of rinsing time on the accuracy of DLP-produced interim crowns support the following conclusions:

The external, intaglio, and marginal surface accuracy of interim crowns were affected differently depending on the rinsing time. Interim crowns treated with 10 minutes of rinsing showed high accuracy. In order to be applied clinically, additional studies using various rinsing materials and methods are needed.

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