INTRODUCTION

The increasing use of digital scanners in dentistry requires that they generate accurate and reproducible models at each scan (high repeatability)\(^1,2\). Conventional prosthetic fabrication methods require the establishment of a model by pouring stone into an impression from a patient. However, this method is neither cost-effective nor rapid\(^3\). To overcome these limitations, intraoral scanners have been used to create models for prostheses fabrication; however, this scanning method has not been reported to have high repeatability of results\(^4,5\). For these reasons, the development of reliable methods to obtain three-dimensional impressions of a patient’s oral structures using an extraoral scanner is increasingly important\(^3-6\).

Scanning a stone model using an extraoral scanner is a common approach, and previous studies have shown a higher repeatability of stone model scanning than that of impression scanning\(^1,3,7\). Recently, blue LED scanners have been developed that can scan both models and impressions with high stability, even in narrow and deep shapes, and at a high speed. However, no studies have examined the repeatability of the scans of stone models and impressions using a blue LED scanner.

Therefore, in this study, we evaluated the repeatability of scans of stone models and impressions of abutment teeth created using a blue LED scanner, and compared the findings between different types of abutment teeth.

MATERIALS AND METHODS

Preparation of the impression and abutment teeth models

Maxillary molars and the next anterior teeth were selected for scanning. In other words, standardized forms (AG-3, Frasaco, Germany) of maxillary canines, premolars, and molars, were generated for these teeth types. One-way analysis of variance (ANOVA) and independent t-tests were performed to evaluate the repeatability of scans of the stone models and impressions obtained from a blue LED scanner. Our results indicate a high repeatability of scans of stone models and impressions of abutment teeth using the blue LED scanner and suggest a possible clinical advantage for scanning impressions of different abutment teeth types.

Keywords: Blue LED scanner, Impressions, Stone models, Three-dimensional evaluation, Superimposing
After these steps, impressions of the titanium abutment teeth were prepared using extra light body rubber impression material indicated for scanning purposes (Aquasil Ultra, Dentsply, St. York, PA, USA). We used Type IV stone (Fujirock EP, GC Europe N.V, Leuven, Belgium) to fill the impressions, which produced an abutment teeth stone model that can be scanned by the blue LED scanner.

**Scanning of the abutment teeth stone models and impressions**

To confirm repeatability of the stone model scan produced using the blue LED scanner (Identica blue, Medit, Seoul, South Korea), the canine stone model was fixed onto the table inside of the blue LED scanner. This was followed by scanning 5 times without moving the stone model to obtain three-dimensional shape data (STL file). The scans of the stone models of the other teeth (molars and premolars) were also evaluated for repeatability using the same procedure (n=5 scans per tooth type). This same process was used to confirm the repeatability of the scans of abutment teeth impressions produced by the blue LED scanner. Through this process, we obtained STL files of impressions for each of the canines, premolars, and molars (n=5 scans per tooth type). Unnecessary portions of each scan under the margin were removed in the STL file for each impression of the abutment teeth obtained.

**Analysis using the software**

We confirmed the repeatability of scans for each tooth using the CopyCAD7.350 SP3 (Delcam plc., Birmingham, UK) software as follows. The point clouds of all the scans (ASCII file) were converted to STL files. To confirm the repeatability of the scans of stone models obtained using the blue LED scanner, a report and a color-difference map were obtained using PowerInspect2012 (Delcam plc.), which superimposed the STL files on the point cloud (ASCII file) (Fig. 2). The same method was used for checking repeatability of the scans of the impressions obtained using the blue LED scanner, and a report and color-difference map were acquired (Fig. 2).

The point clouds for five scans of the stone models of each abutment tooth were superimposed simultaneously on the respective STL files, and the best fit was determined (n=10 per type). The discrepancy was defined as the distance between superimposed two 3-D images produced by the same method and the same tooth type. The size of difference means the degree of repeatability of scanners because the images were produced by an identical method and material. Ten color-difference-maps and reports (n=10 per tooth type) were obtained for the canines (Stone model of Canine; SC), premolars (Stone model of Premolar; SP) and molars (Stone model of Molar; SM), respectively. This method was also used to confirm the repeatability of the scans of the impressions. Ten color-difference-maps and reports (n=10 per tooth type) were obtained for the canines (Impression of Canine; IC), premolars (Impression of Premolar; IP), and molars (Impression of Molar; IM), respectively.

**Statistical analysis**

The data showed a normal distribution, and two parametric statistical techniques were used to confirm the repeatability of the scans of the abutment teeth stone models and impressions, obtained using the blue LED scanner. One-way analysis of variance (ANOVA) was used to evaluate the repeatability of the scans of the stone models and impressions with regard to tooth type. Post-hoc comparisons were performed using Tukey’s HSD test (n=1 per type, total n=4) (Tables 1 and 2). Further, the independent t-test was used to compare the difference of the repeatability of the scans of stone models and impressions according to tooth type (n=1 per type, total n=6) (Table 3). The alpha error level was set at 0.05. All statistical analyses were performed using SPSS version 21.0 (SPSS, Chicago, IL, USA) (Tables 1, 2 and 3).
Fig. 2 Evaluation of the repeatability of blue LED scanning for the 3 types of abutment teeth in stone models and impressions.

Color difference map of the canine stone model showing the superimposing of three-dimensional data (a). Color difference map of the premolar stone model showing the superimposing of three-dimensional data (b). Color difference map of the molar stone model showing the superimposing of three-dimensional data (c). Color difference map of the canine impression showing the superimposing of three-dimensional data (d). Color difference map of the premolar impression showing the superimposing of three-dimensional data (e). Color difference map of the molar impression showing the superimposing of three-dimensional data (f). Yellow or red represents a positive error, turquoise to blue represents a negative error, and green represents good fit.

<table>
<thead>
<tr>
<th>Teeth type</th>
<th>Mean of the discrepancies (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>2.9 (2.4–3.4)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>2.9 (2.2–3.6)*</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>2.6 (2.1–3.1)*</td>
<td></td>
</tr>
<tr>
<td>Impression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>4.4 (3.9–4.9)*</td>
<td></td>
</tr>
<tr>
<td>IP</td>
<td>2.9 (2.2–3.6)*</td>
<td></td>
</tr>
<tr>
<td>IM</td>
<td>3.2 (2.9–3.5)*</td>
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</tbody>
</table>

*Different letters indicate significant differences at an alpha level of 0.05.

<table>
<thead>
<tr>
<th>Teeth type</th>
<th>RMS of the discrepancies (95% CI)</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Stone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC</td>
<td>16.9 (9.2–24.6)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>14.8 (11.2–18.4)*</td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>15.1 (11.5–18.7)*</td>
<td></td>
</tr>
<tr>
<td>Impression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>9.8 (8.7–10.9)*</td>
<td></td>
</tr>
<tr>
<td>IP</td>
<td>10.6 (6.3–15.0)*</td>
<td></td>
</tr>
<tr>
<td>IM</td>
<td>11.2 (9.3–13.1)*</td>
<td></td>
</tr>
</tbody>
</table>

*Different letters indicate significant differences at an alpha level of 0.05.
RESULTS

Figure 3 shows the quantitative data of the mean of the discrepancies and the RMS (root mean square) of the discrepancies between scans of the stone models and the impressions, obtained using the blue LED scanner. For the stone models, the mean of the discrepancies in the scans of SCs, SPs, and SMs was 2.9 µm (95% confidence interval [CI], 2.4–3.4), 2.9 µm (95% CI, 2.2–3.6), and 2.6 µm (95% CI, 2.1–3.1), respectively. No significant differences were observed in the mean of the discrepancies in the scans of the stone models and those in the scans of any tooth type (p=0.64). For the impressions, the mean of the discrepancies in the scans of ICs, IPs, and IMs was 4.4 µm (95% CI, 3.9–4.9), 2.9 µm (95% CI, 2.2–3.6), and 3.2 µm (95% CI, 2.9–3.5), respectively. The mean of the discrepancies in the scans of the ICs showed a significant difference when compared to that of the other teeth (p<0.001).

The RMS of the discrepancies in the scans of SCs, SPs, and SMs was 16.9 µm (95% CI, 9.2–24.6), 14.8 µm (95% CI, 11.2–18.4), and 15.1 µm (95% CI, 11.5–18.7), respectively. No significant difference was observed with regard to any tooth type (p=0.80). The RMS of the discrepancies in the scans of ICs, IPs, and IMs was 9.8 µm (95% CI, 8.7–10.9), 10.6 µm (95% CI, 6.3–15.0), and 11.2 µm (95% CI, 9.3–13.1) respectively, with no significant difference observed with regard to any tooth type (p=0.73).

A comparison of the mean and RMS of the discrepancies was performed to confirm the difference in repeatability of scans between the stone models and impressions (Table 3). The mean of the discrepancies in the scans of the stone models and the impressions of the canines and molars showed a significant difference (p<0.001 and p=0.03, respectively), but there was no significant difference between the stone models and the impressions of the premolars (p=1). Similarly, the RMS of the discrepancies in the scans of the stone models and the impressions of the canines and molars showed a significant difference (p<0.05 and p=0.04, respectively), but there was no significant difference observed with regard to any tooth type (p=0.11).

Figure 2 shows the qualitative data obtained using color-difference-maps, which compares the repeatability of the scans of stone models and the impressions of each tooth generated by the blue LED scanner.
(c) exhibit mostly green color, which indicates that no significant error was observed (Fig. 2). In the case of the impressions, the ICs (d), PCs (e), and MCs (f) also exhibit green color. However, negative errors (blue) and positive errors (red) mostly appear frequently for the canines and molars on all the tooth surfaces, except the occlusal surface (Fig. 2).

**DISCUSSION**

In this study, we compared the scanning repeatability of the recently developed blue LED scanner with the stone models and impressions of different abutment teeth types (Figs. 2 and 3). The mean of the discrepancies in the scans of the stone models, obtained from the blue LED scanner, showed no statistically significant difference. However, the mean of the discrepancies in the scans of the impressions, obtained from the blue LED scanner, showed a statistically significant difference for the canines (Table 1). This difference is attributed to the morphological characteristics of the canines, which have a narrow and deep shape and show shadows the most (Fig. 2). So, in comparison with previous study of white light scanner for repeatability of impressions, the result showed a higher mean of the discrepancies about 2–6 µm from blue LED scanner for repeatability of impressions than white light scanner for repeatability of that, showed a higher RMS of the discrepancies about 7–15 µm from blue LED scanner for repeatability of impressions than white light scanner for repeatability of that.\(^5\)

The RMS of the discrepancies in the scans of stone models and the impressions, obtained from the blue LED scanner, showed no statistically significant difference (Table 2). This result indicates that the repeatability of the scans of stone models and the impressions obtained from the blue LED scanner was high.

We also compared the mean and RMS of the discrepancies to confirm the difference between the stone models and impressions in scanning repeatability (Table 3). The mean and RMS of the discrepancies in the scans of the stone models and the impressions of canines and molars showed a significant difference, while the premolars did not show a significant difference. The RMS of the discrepancies in the scans of the stone models showed greater errors than that of the impressions (Table 3). The errors resulted from reflection and scattering of light that may occur during scanning with blue LED scanner.\(^13\)

In this study, a rubber impression material (Aquasil Ultra, Dentsply) of the vinyl polysiloxane system was used to improve reliability of the measurements and the repeatability of the scans. This impression material was developed and optimized for optical scanning, and was used in our study in order to improve validity in the evaluation of repeatability of the impression scans.\(^5\)

We selected canines, first premolars, and first molars because canines represent anterior teeth, while the first molars show representative characteristics of molars.\(^5\) The first premolars have characteristics of both anterior teeth and molars.

Many recent studies have evaluated the repeatability of scans of the full arch.\(^6,10\) However, in the case of research on the repeatability of full arch model scans, it was difficult to determine errors in the abutments that are most important for prosthesis fabrication. Therefore, in this study, we selected an impression body for each abutment tooth.\(^1,4,7,16,17\) Previous studies showed that the repeatability of the stone model scanning was higher, in general, than that of impression scanning.\(^5,6\) However, the results of the present study suggest a clinical advantage of the impression scanning over stone model scanning using the blue LED scanner.

This study has several limitations. First, the method applied a conventional two-dimensional measurement process to the three-dimensional superimposing method to verify repeatability. It is difficult to explain the errors in the best fit alignment process, which verifies errors between the data\(^2,5,15,18\) and to investigate whether the error in the best fit alignment process occurs in the verification process or in the process of scanning.\(^7\) In addition, it is challenging to explain the errors resulting from reflection and scattering of light that may occur during scanning with blue LED scanner, including errors that were induced by the program.\(^1,4,5,7,19\) Future studies are required to overcome these limitations, to discover means of reducing error in the three-dimensional superimposing method, and to improve the quality of the impression scans obtained using the blue LED scanner.

**CONCLUSION**

The results of this study show a high repeatability of the scans of the stone models and impressions obtained using a blue LED scanner, and suggest a possible clinical advantage of impression scanning over stone model scanning for different abutment teeth types.

**ACKNOWLEDGMENTS**

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