https://doi.org/10.4047/jap.2024.16.5.311

The effects of different lighting conditions on the accuracy of intraoral scanning

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PURPOSE. This study aimed to investigate the extent to which intraoral scanning are affected by clinical conditions, and whether ambient lighting and different color temperatures have an impact on the accuracy of intraoral scanner, as well as to evaluate scanning time. **MATERIALS AND METHODS.** Twelve different environments were created using various ambient lighting conditions (0, 500, 1000 and 1500 lux) and color temperatures (white, blue and yellow). A partially edentulous mandibular model with two implants and a three-unit bridge was scanned under each environment until 10 digital models were obtained, and scanning times were recorded using a virtual stopwatch. A 3D analysis was performed on the obtained digital models, and the data were analyzed using a software. The generalized linear model analysis and Tukey multiple comparison test were used to analyse the data ($P < .05$). **RESULTS.** The effect of lux, color temperature, and scanning times on RMS data was found to be significant ($P < .001$). The mean RMS value was the highest in the 0 lux group and the lowest in the 500 lux group. Regarding the color temperature, the highest RMS value was in the white color group and the lowest in the yellow color group. Scanning times were similar among the 0, 500 and 1000 lux groups, with a significant increase in the 1500 lux group. **CONCLUSION.** Different ambient lighting conditions and color temperatures have significant effect on the accuracy of intraoral scanning. [J Adv Prosthodont 2024;16:311-8]

KEYWORDS
Ambient light; Color temperature; Intraoral scanning

INTRODUCTION

In contemporary clinical dental practice, the utilization of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies has rapidly increased.[1] The initial step involves surface scanning of teeth and related tissues using an intraoral scanner (IOS). In the CAD-CAM digital workflow,

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Received August 3, 2024 /
Last Revision September 25, 2024 /
Accepted October 22, 2024

https://doi.org/10.4047/jap.2024.16.5.311

digital scanning technologies offer high accuracy for both implant- and tooth-supported restorations when compared to traditional impression techniques.[1-3]

Digital impression has numerous advantages such as improving patient acceptance, reducing distortion of impression materials, and visualizing preparation in three dimensions beforehand, all while being cost-effective and time-efficient.[4] Moreover, digital impression, devoid of harmful stimuli, ensures high patient satisfaction by eliminating the risk of choking, gagging, and taste irritation,[5] thereby reducing the treatment time.[6-10] With the advancement of intraoral scanners, there has been rapid progress in the accuracy of digital impression. The accuracy of digital impression is determined by its trueness and precision.[11] Trueness refers to the deviation of the scanned data from the original geometry, while precision refers to the deviation between repeated scans of the same data.[12-14] Minimizing adaptation problems in prostheses is the focus of many current studies to ensure prosthetic restorations are made with minimal errors independently of the dentist and technician.[15]

While there are studies comparing intraoral scanners internally,[2,3,7,9] research on environmental factors affecting the digital workflow is scarce. Various factors such as user experience and learning process affect the sensitivity of digital scanning.[16,17] Additionally, factors such as calibration,[18] scanning protocol,[19] ambient lighting conditions,[20] surface characteristics,[21-24] presence of mobile tissues,[25] presence of reflective restorations, and presence of saliva also influence the accuracy. Revilla-Leon *et al*.[26] reported that ambient lighting conditions significantly affect the geometry replication capability of an intraoral scanner. Therefore, this study was aimed to investigate the extent to which intraoral scanning is influenced by environmental conditions in clinical settings, as well as to determine whether the intensity of ambient lighting and different color temperatures have an impact on the accuracy of intraoral scanner. The null hypothesis of the study was that varying ambient lighting conditions and color temperatures would have no effect on the accuracy of intraoral scanning.

MATERIALS AND METHODS

As a reference model, a fully dentate mandibular model (Frasaco Study Model ANA 4; Frasaco GmbH, Tettnang, Germany), produced for multipurpose in dentistry, was used in this study. In the preparation of the implant area on the reference model, teeth 44, 45, and 46 were removed from the model, and digital implant analogs (Osstem TS; Osstem Implant Co. Ltd., Seoul, Korea) were placed in the areas of teeth 44 and 46.

In the preparation of the teeth, teeth 34 and 36 were removed from the model, and teeth 33, 35, and 37 were prepared with a chamfer bur according to preparation principles, including a convergence angle of 6 – 10 degrees, circumferential reduction of 1.2 – 1.5 mm, a step width of 1 mm, and occlusal reduction of 2 mm. Pink silicone (Gingifast Rigid; Zhermack GmbH, Badia Polesine, Italy) was applied to mimic the periodontal tissue around the analogs and in the socket areas of teeth 45, 36, and 34 until it reached the level of the gingival line. All analogs and prepared tooth were positioned to the same level, assumed to be the gingival line level.

A laboratory scanner (3Shape E3; 3Shape, GmbH, Copenhagen, Denmark) was used for the reference model acquisition. The scan bodies (Osstem TS; Osstem Implant Co. Ltd., Seoul, Korea) were placed on the prepared model, and the scanning process was initiated using the laboratory scanner. The scanning process was repeated 10 times, and the obtained scanning data were overlapped using reverse engineering software, (Geomagic Design X 3D System Inc., Rock Hill, SC, USA), to ensure the accuracy of the data.

To mimic clinical lighting conditions, 4 different ambient lightings (0 lux (dark), 500 lux, 1000 lux, 1500 lux), and 3 different light sources (white light (7500 K), blue light (19000 K), yellow light (3900 K)) were used in this study.

For ambient lighting, a setup with 12 white LED bulbs (Panasonic LED E27 860 lumens 6500 K White; Panasonic Corporation, Osaka, Japan) was prepared with 12 sensors, overlooking the scanning area. The ambient lighting was measured and adjusted to 0 lux, 500 lux, 1000 lux, and 1500 lux using a light meter (DT-3809 Led Light Meter; Shenzhen Everbest Machinery Industry Co. Ltd., Shenzhen, China) (Fig. 1). Three dif-

Fig. 1. Lux measurements of lighting environments.

Fig. 2. Color filters: White (7500 K), Blue (19000 K), and Yellow (3900 K).

ferent color temperatures were obtained by adding a conversion filter to the tip of a portable reflector, resulting in desired colors: white (7500 K), blue (19000 K), and yellow (3900 K) (Fig. 2). Thus, a total of 12 possible lighting conditions were created. All environments were created in a windowless, naturally lit (NL), and dark room.

In this study, an intraoral scanner (YOUJOY 3DS 2.0; Youjoy Co. Ltd., Ningbo, China) was used. The scanning process was performed according to the scanning recommendation protocol of the manufacturer. The scanning process was repeated 10 times for each environment, and after each scan, the scanned surfaces were examined, areas with artifacts were identified and cut by cleaning, and scanning times were recorded in seconds using a virtual stopwatch of intraoral scanner. Finally, the scans were saved and stored as standard tessellation language (STL) files.

To compare the measurements, all STL files obtained from the scanner were transferred to a reverse engineering software (Geomagic Design X 3D System Inc., Rock Hill, SC, USA). The transferred data were standardized by performing initial alignment and best alignment according to the reference-accepted regions through the program (Fig. 3). Subsequently, the obtained data were saved as RMS data. The data were analyzed using a software (IBM SPSS V23; SPSS Inc., Chicago, IL, USA). Normal distribution compliance was examined with the Shapiro Wilk test. Generalized Linear Models were used for the comparison of parameters conforming to normal distribution by color and lux, and multiple comparisons were made using the Tukey Test. The significance level was set at $P < .05$.

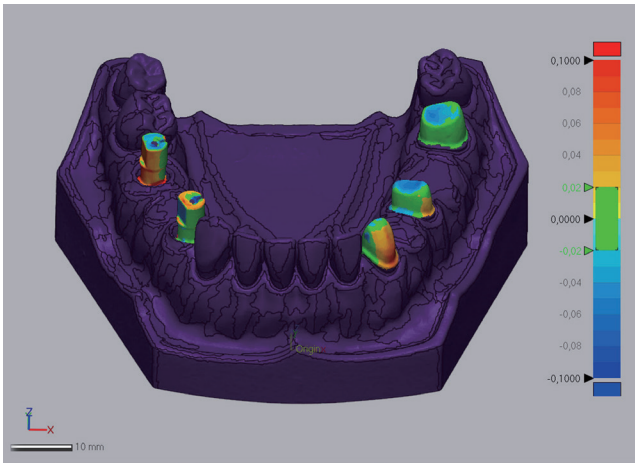

Fig. 3. Image of superimposed STL files.

https://doi.org/10.4047/jap.2024.16.5.311

RESULTS

The main effect of color groups and lux was found to be statistically significant on the RMS data ($P < .05$). The interaction between color groups and lux did not have a statistically significant effect on the mean RMS values ($P = .348$). The mean RMS value was 0.0658 in the white color group, 0.0599 in the blue color group, and 0.0544 in the yellow color group. The mean RMS value was 0.0852 in the 0 lux group, 0.0393 in the 500 lux group, 0.0419 in the 1000 lux group, and 0.0736 in the 1500 lux group. Independent of lux value, the mean RMS value obtained from the white color was significantly higher than those from other colors ($P < .001$). The mean RMS value obtained from the blue color was also significantly higher than that from the yellow color ($P < .001$). In the 0 lux group, the mean RMS value was significantly higher compared to all other lux values ($P < .05$). While there was no statistically significant difference between the 500 and 1000 lux values ($P > .05$), both values showed significantly lower RMS values compared to the 1500 lux value ($P < .05$). In the 0 lux group, similar RMS values were obtained in the white and blue colors ($P > .05$), while a significantly lower RMS value was found in the yellow color ($P < .05$) (Table 1).

The main effect of color groups was not statistically significant on time ($P = .431$). The mean time was 265.4 seconds in the white color, 268.7 seconds in the blue color, and 266.1 seconds in the yellow color. The main effect of lux was statistically significant on time ($P < .001$). The mean time was 260.5 seconds in the 0 lux group, 259.4 seconds in the 500 lux group, 263.3 seconds in the 1000 lux group, and 283.6 seconds in the 1500 lux group. The mean time in the 1500 lux group was the highest and differed from the other groups. The 0, 500, and 1000 lux groups showed similarity in terms of time. The interaction between color groups and lux was not statistically significant on time ($P = .388$) (Table 2).

DISCUSSION

In this study, the accuracy of digital impression of implant-supported and fixed prosthetic restorations under different ambient lighting conditions and color

Table 1. Descriptive statistics and multiple comparison results of RMS (mm) values according to Color and Lux

Lux	Color			
	White	Blue	Yellow	Total
0	0.0907 ± 0.006	0.0876 ± 0.005	0.0774 ± 0.0045	0.0852 ± 0.0077[a]
500	0.0457 ± 0.0051	0.0383 ± 0.0048	0.0341 ± 0.0057	0.0393 ± 0.007[c]
1000	0.0475 ± 0.0054	0.0421 ± 0.0051	0.0363 ± 0.0058	0.0419 ± 0.007[c]
1500	0.0792 ± 0.0059	0.0716 ± 0.0056	0.07 ± 0.0062	0.0736 ± 0.007[b]
Total	0.0658 ± 0.0206[a]	0.0599 ± 0.0214[b]	0.0544 ± 0.0204[c]	0.06 ± 0.0212

Mean ± standard deviation, a-c: There is no significant difference between main effects with the same letter.

Table 2. Descriptive statistics and multiple comparison results of times values (sec) in seconds according to Color and Lux

Lux	Color			
	White	Blue	Yellow	Total
0	262 ± 12.8	261.6 ± 14	257.8 ± 12.9	260.5 ± 12.9[b]
500	257.4 ± 9.7	265.4 ± 16.2	255.5 ± 9.9	259.4 ± 12.6[b]
1000	257.6 ± 13.2	264.7 ± 15.1	267.5 ± 10.7	263.3 ± 13.4[b]
1500	284.4 ± 7.9	283.1 ± 10.4	283.4 ± 9.9	283.6 ± 9.2[a]
Total	265.4 ± 15.5	268.7 ± 16	266.1 ± 15.3	266.7 ± 15.6

Mean ± standard deviation, a-b: There is no significant difference between main effects with the same letter.

temperatures has been evaluated. This study refused the null hypothesis that varying ambient lighting conditions and color temperatures have no effect on the accuracy of intraoral scanning.

When the results of this study were examined in terms of lux values, within each color group, the 0 lux values showed significantly higher RMS values compared to all other lux values. Similarly, ambient values of 1500 lux also showed significantly higher RMS values compared to 500 lux and 1000 lux values. There was no statistically significant difference between 500 and 1000 lux values. Lux values were determined in our study considering clinical conditions. The 500 lux value represents classic room lighting in a dental clinic, while values of 1500 lux and above represent dental unit reflector lighting.[27] Furthermore, the 500 lux value was seen as a value measured in average room light and was added as a parameter. Examination of the data concluded that clinical lighting conditions (500 and 1000 lux) were appropriate for the scanner to perform optimally. In a similar study, digital scans were performed under 0 lux and 1003 lux ambient illuminations, where the 1003 lux condition yielded the lowest deviation values, while 0 lux resulted in higher RMS values.[28] In another study, illuminations of 0 lux, 500 lux, and 2500 lux were used, and an average deviation value was found significantly lower at 500 lux compared to 0 and 2500 lux. These findings are consistent with the results of the present study.

In a previous study that evaluated the impact of various lighting conditions on the mesh qualities of different IOS devices, three different IOS devices were evaluated under four different lighting conditions.[26] Scans were conducted in environments created with operating room light at 10000 lux, room light at 1003 lux, natural light at 500 lux, and no light at 0 lux. The different IOS devices showed significant differences in mesh quality values in scans conducted under different lighting conditions but with the same illumination conditions and using the same IOS.[26] The findings of this study were similar to a previous study,[26] with the highest RMS values obtained in the 0 lux environment. In another study conducted by Revilla-Leon *et al*.,[29] environmental lighting conditions were tested up to 10000 lux in increments of 1000 lux, forming ten groups based on different brightness levels. The 1000 lux lighting condition was found to be ideal for maximizing the scanning accuracy of the tested IOS, and it was recommended to avoid dental unit light. In another study examining ambient illuminations of various intensities (100, 500, 1000, 5000, and 10000 lux) for different intraoral scanners in full-arch implant scans, seven different IOSs were evaluated. It was concluded that changes in ambient lighting conditions had a significant effect on scanning accuracy and scanning time, but this effect varied for all IOSs used.[30]

When the results of the present study were examined in terms of color values, within each lux group, the RMS value obtained from the white color was significantly higher than those from other colors. The RMS value obtained from the blue color was also significantly higher than that from the yellow color. The mean RMS values differed across all color groups. Overall, the lowest RMS data were obtained at 3900 K (yellow), followed by 19000 K (blue), and finally 7500 K (white). In the dark ambient group, statistically similar RMS values were obtained at 7500 K (white) and 19000 K (blue), while significantly less RMS data were obtained at 3900 K (yellow). In this study, when determining color temperatures, 3900 K (yellow) was chosen to mimic daylight in a windowed clinic. The 7500 K (white) color temperature was added as a parameter to mimic the color of the dental reflector light found in contemporary dental units and the 19000 K (blue) light was selected as a third parameter. In a study conducted by Köseoğlu *et al*., digital scans were performed using two different scanning light modes, blue and white, under different ambient illuminations. The blue mode condition had the lowest deviation values, while the white mode condition yielded higher deviation data.[28] In a similar study, scans were performed at different lux values under color temperatures of 3900 K (yellow), 4100 K (orange), 7500 K (white), and 19000 K (blue), and it was found that the 3900 K (yellow) color temperature was optimal for obtaining digital impressions. The 4100 K (orange) color temperature was found to be superior to 7500 K (white) and 19000 K (blue).[20] Although the optimal color temperature of 3900 K (yellow) aligns with the present study, the similarity of the 7500 K (white) and 19000 K (blue) color temperature data does not corre-

https://doi.org/10.4047/jap.2024.16.5.311

spond to the present study. These differences may be associated with the different intraoral scanner used in the other study.

When the results of the present study were examined in terms of scanning times, within each lux group, the primary effect of lux was found to be statistically significant on scanning time. The average time in the 1500 lux group was the highest and differed from the other groups. The 0 lux, 500 lux, and 1000 lux groups showed similarity in terms of time. There was no statistically significant interaction between color and lux on time.

Parallel to the present study, in a study by Wesemann *et al*.,[31] six intraoral scanners were used, and scans were performed at different lighting levels with each IOS. In all scans, scanning times were recorded and it was observed that scanning time increased for all IOSs except iTero Element in scans performed above 500 lux. Additionally, the shortest scanning time for each scanner varied. In another study by Arakida *et al*., scanning times were examined under ambient illuminations of 0 lux, 500 lux, and 2500 lux, and it was found that scanning time was significantly longer at 2500 lux compared to the other scans.[20] This longer scanning time is associated with the effect of ambient light on the accuracy of digital impression, related to the three-dimensional (3D) data acquisition process.[32] Most optical scanners obtain 3D data by reflecting laser light onto the surface of the original geometry and capturing this reflected light in a high-speed circuit. However, when the brightness of the laser light is too high, the sensor becomes saturated, resulting in the system being unable to calculate the positions of points. Moreover, a laser with high brightness may cause partial errors at points and delay the capture of data.[33]

In terms of ambient lighting conditions and color temperatures, the lowest RMS values were obtained at 500 lux and 3900 K (yellow), which are the closest to clinical conditions. This was followed by data obtained at 1000 lux. The highest average RMS values were obtained in a 0 lux (dark) environment and at a 7500 K (white) color temperature. Therefore, it was concluded that appropriate clinical lighting conditions and yellow color temperature were necessary for the scanner to perform optimally.

Although efforts were made to create a scenario close to clinical conditions in this study, there were some limitations. Factors such as the moist and warm environment inside the oral cavity, as well as patient-related factors such as saliva and tongue, may increase deviation in a similar *in vivo* study. Additionally, mobile mucosal areas in edentulous areas may lead to significant errors in processing data and affect the scanning time. All these factors can negatively affect the measurement quality of a scanner. Although the RMS values obtained were carried out by a single clinician, errors related to the clinician can be considered as a limitation. Thus, further researches are needed.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

A higher RMS value was obtained at 0 lux compared to all other lux values. While there was no statistical difference between the 500 and 1000 lux values, both values showed significantly lower RMS values than the 1500 lux value. Regardless of the lux value, the RMS value obtained from 7500 K (white) color was significantly higher than other colors. The RMS value obtained from 19000 K (blue) color was also significantly higher than the RMS value obtained from 3900 K (yellow) color. The time average in the 1500 lux group was found to be the highest and differed from other groups. The 0, 500, and 1000 lux groups showed similarity in terms of time. The color groups had no effect on the scanning time.

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