THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Influence of the ambient color lighting on the accuracy of complete arch implant scans recorded by using two intraoral scanners

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ABSTRACT

Statement of problem. The influence of different ambient factors including lighting has been previously studied. However, the influence of ambient color lighting settings on intraoral scanning accuracy remains uncertain.

Purpose. The purpose of this in vitro study was to assess the influence of ambient color lighting on the accuracy of complete arch implant scans recorded by using 2 intraoral scanners (IOSs).

Material and methods. An edentulous maxillary cast with 6 implant scan bodies was digitized by using a laboratory scanner (DW-7–140) to obtain a reference file. Two groups were created based on the IOS tested: TRIOS 4 (IOS-1) and i700 (IOS-2). Seven subgroups were developed depending on the ambient color lighting (red, green, blue, yellow, cyan, magenta, and white) (n=15). Scanning accuracy was analyzed by using a metrology software program (Geomagic Control X). The Kruskal-Wallis, 1-way ANOVA, and pairwise comparisons were used to analyze the data (α=.05).

Results. Significant trueness and precision values were found across the groups (*P*<.05) and subgroups (*P*<.05). For IOS-1, blue ambient lighting obtained the best trueness (19.8 ±1.8 μm) (*P*<.05); in precision, white light (20.8 ±7.3 μm) and blue light (22.1 ±13.5) showed the best results (*P*<.05). For IOS-2, white light showed the best trueness (51.9 ±16.7 μm); the best precision was obtained under magenta (38.6 ±10.4 μm) and yellow light (52.6 ±24.0 μm) (*P*<.05).

Conclusions. The optimal ambient color lighting varied between the IOSs assessed. As the best condition for maximizing accuracy was not found, ambient color lighting must be individualized for the IOS system used. (J Prosthet Dent 2025;133:552-559)

Intraoral scanners (IOSs) provide a reliable method for fabricating crowns and short-span tooth- and implant-supported fixed dental prostheses.[1–3] However, the accuracy of complete arch implant scans is uncertain.[4,5] Different scanning techniques have been described to improve the accuracy of complete arch implant scans recorded by using IOSs.[6–12] A clinically acceptable implant-prosthodontic interface discrepancy between 150 μm[13] and 200 μm[14] has been described.

Different patient- and operator-related factors can impact the accuracy of IOSs.[15–17] Among patient-related factors, edentulous areas, implant positions, and implant scan bodies (ISBs) are influencing factors that can reduce complete arch implant scans.[17] The digital recording of edentulous areas can be challenging because of limited anatomic landmarks and the mobility of alveolar mucosa.[18–20] Furthermore, interimplant distance and implant position (depth, angulation, and location in the dental arch) impact intraoral scanning accuracy.[15–22] Operator-related factors include operator skill and decisions that influence the accuracy of IOSs such as ambient lighting,[23–33] ambient temperature changes,[34] scanning distance,[35,36] and scanning pattern.[37–44]

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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Clinical Implications

For optimal accuracy of complete arch intraoral implant digital scans, the ambient light color should be chosen according to the intraoral scanner system used.

Previous studies have reported the impact of ambient light illuminance on the scanning accuracy,[23,24,27,29,31–33] scanning time,[24] and mesh quality[25,28] of intraoral scans recorded in completely dentate conditions and complete arch implant scans.[30] Revilla-León et al[29] evaluated different ambient illuminances (0, 500, 1003, and 10 000 lux) on the scanning accuracy of 3 IOSs (TRIOS 3, iTero Element, and Cerec Omnicam), reporting that the optimal lighting condition varied depending on the IOS tested. Koseoglu et al[23] tested the impact of 2 ambient lighting conditions (0 and 1000 lux) on one IOS (i500; Medit), reporting better trueness under 1000 lux. Wesemann et al[24] evaluated 6 IOSs (TRIOS 3, Cerec Omnicam, iTero Element, CS 3600, Planmeca Emerald, and GC Aadva) under different illuminances, reporting that the scans with the TRIOS 3 had the lowest deviation accuracy under varied lighting conditions. Therefore, based on the reported data, the optimal lighting condition for maximizing the accuracy of IOSs varies depending on the IOS selected.[23,24,27,29,31–33]

The literature describing the influence of ambient color lighting on the accuracy of IOSs for complete arch implant scans is scarce.[27] The aim of this in vitro study was to evaluate the influence of different ambient color lighting (red, green, blue, yellow, cyan, magenta, and white) on the accuracy of 2 IOSs (TRIOS 4 and i700). The null hypotheses were that no significant trueness and precision discrepancy would be found among the complete arch implant scans recorded by using the 2 IOSs tested under the 7 ambient color lighting conditions and that no significant trueness and precision discrepancy would be found among the complete arch implant scans recorded by using the 2 IOSs tested under the same ambient color.

MATERIAL AND METHODS

A maxillary edentulous cast with 6 internal hexagonal connection dental implants (Ocean IC; Avinent) and artificial gingiva was selected (U-007A; Bone Models). The implants were located on the right and left lateral incisors, first premolars, and first molars. Six implant abutments (Straight transepithelial abutment; Avinent) were tightened at 25 Ncm with a torque wrench (0295; Avinent) by following the manufacturers recommendations. Subsequently, a new 1-piece polyetheretherketone (PEEK) ISB with a flat surface of geometry bevel (scan body 2800; Core 3D centers) was placed on each implant abutment with the geometry bevel oriented to the lingual surface[45] and tightened to 15 Ncm according to the manufacturer's instructions (Fig. 1). The ISBs were maintained in the same position until all the digital scans had been completed.

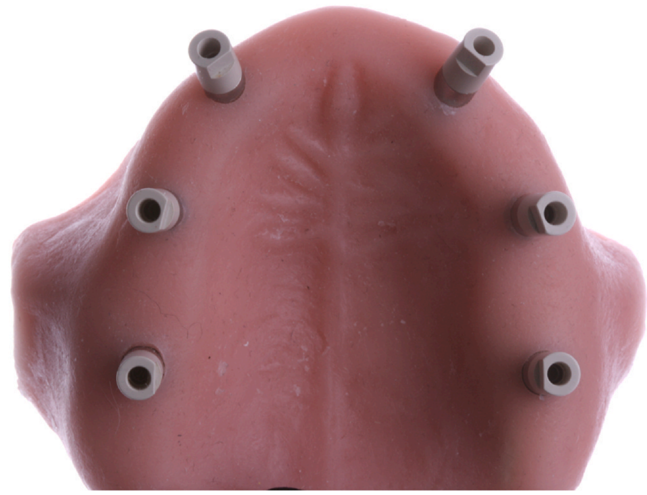

Figure 1. Occlusal view of maxillary cast with implant scan bodies.

The implant cast was digitized by using a desktop laboratory scanner (DW-7–140, 7 Series; Dental Wings) according to the manufacturer's instructions. The manufacturer of the desktop laboratory scanner reported an accuracy of 15 μm. A standard tessellation language (STL) file was obtained and used as the reference (control) file.

Two different groups were created based on the IOS selected: IOS-1 (TRIOS 4, wireless, v.1.7.31.1; 3Shape A/S), and IOS-2 (i700, wireless, v. 3.0.1; Medit). Each group was divided into 7 subgroups depending on the ambient color lighting tested: red, green, blue, yellow, cyan, magenta, and white (n=15). A white light obtained by white beads with a temperature color of 4400 K, and 6 ambient color lighting conditions were established by configuring the red, green, and blue (RGB) parameters of beads to obtain the primary colors of red, green, and blue and by combining these to obtain the secondary colors of yellow, cyan, and magenta.

For each ambient color lighting condition on both IOSs, a total of 15 consecutive intraoral digital scans were recorded. Sample size was determined based on previous studies,[29,30,32,33] and sample size calculation with a power analysis software program (G*Power v3.1.9.7; Heinrich-Heine-Universität Düsseldorf). The sample size was calculated for a minimum power of 80%, effect size of 0.4, and error of α=.05, resulting in an actual power of 83% and a total sample size of 98; therefore, a minimum of 14 scans was determined for each subgroup.

The experimental intraoral scans were recorded by a restorative dentist (G.O.-L.) with 5 years of experience handling IOSs. The IOSs were calibrated before recording began and after every 15 scans according to the

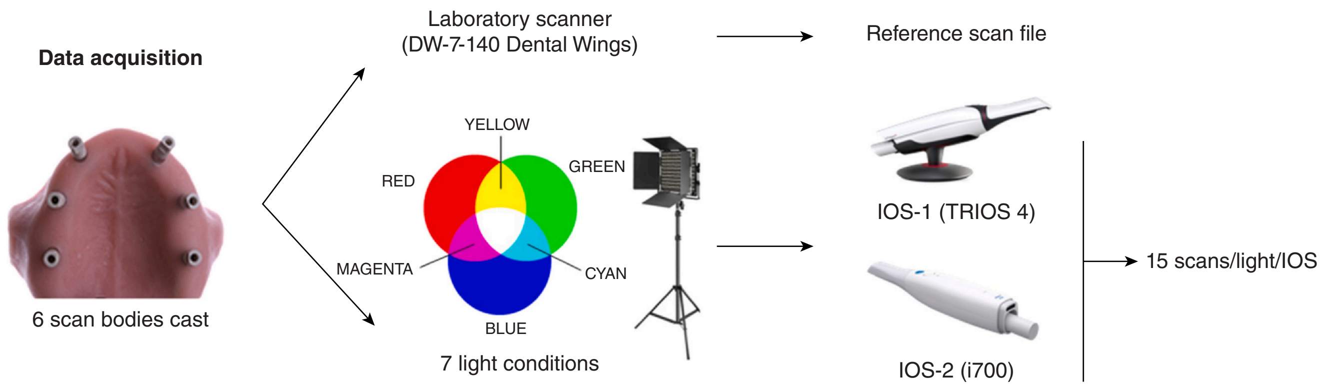

Figure 2. Research protocol.

manufacturer´s calibration protocol and the recommendations of a previous study.[32] All specimens were recorded by using the zig-zag scanning pattern (Fig. 2).[46–49] The scans started on the right posterior ISB moving anteriorly toward the contralateral side with buccal-to-lingual movements. The focal depth of IOS-1 could not be altered by the operator; however, a focal length of 23 mm was selected in the IOS-2. The scanning distance was maintained between 2 and 4 mm in both IOS groups.[36] The specimens were captured without rescanning.[50–53] Additionally, the experimental scans were performed in a room without windows.[25,26,28–30,33] The single ambient light source was a light-emitting diode panel light (660 Pro RGB; Neewer) mounted on a tripod stand. This panel light presented RGB, cool white and warm white beads with adjustable hue, saturation, and intensity parameters controlled by a mobile app via Bluetooth connection (Neewer app, v.4.6.3; Neewer Team). The ambient illuminance condition was maintained at 1000 lux (LX1330B Light Meter; Dr. Meter Digital Illuminance).[29,30,32–34]

The RGB value of the panel light was determined with a mobile app from 0 to 255 to each parameter. Therefore, the subgroup configuration was red light (255–0-0 on RGB values, respectively); green light (0–255-0 on RGB values); blue light (0–0-255 on RGB values); yellow light (255–255-0 on RGB values); cyan light (0–255-255 on RGB values); and magenta light (255–0-255 on RGB values) (Fig. 3).

All specimens were automatically postprocessed by using the IOS software program and exported in an STL file format. The files were imported into a metrology software program (Geomagic Control X; 3D Systems) to assess scanning accuracy. The reference and experimental files were aligned using the iterative closest point best-fit algorithm.[54,55] To analyze the data from the 3D deviations, the root mean square (RMS) error was calculated.[54–56] To assess trueness,[56] the RMS error of the 3D deviation implant position of the scan files created with scan bodies library files were compared with the corresponding reference digital cast (15 comparisons for each subgroup). In contrast, to measure precision[56] 10 random scan files, selected by using the random number tool of a spreadsheet [Excel v18; Microsoft Corp]), of each subgroup were compared with one another, and the deviations were calculated (45 superpositions per subgroup). The discrepancies identified by the software program between each mesh pair comparison were shown through a color-coded map that indicated the directionality of the deviation with a threshold of 100 µm on a color graded scale. Inward deviations with cool shade colors, outward deviations with warm shade colors, and minimal deviations were colored green (±20 µm) (Fig. 4).

Accuracy has been defined as the combination of trueness and precision in the International Organization for Standardization (ISO) 5725–1 standard.[56] Precision indicates the degree of identical images acquired by repeated digital scanning under the same conditions, and trueness is related to the ability to replicate a dental arch as closely as possible to its true dimensions, without distortion or deformation.[56] A statistical software program (IBM SPSS Statistics v26; IBM Corp) was used to analyze the data. Extreme outliers were identified and removed from the data set before performing statistical tests. The Shapiro-Wilk test was used to assess the normality of the data set, and the ANOVA test and the Kruskal-Wallis test followed by the post hoc Bonferroni or Games-Howell test were carried out (α=.05).

RESULTS

The statistical aggregates of mean, standard deviation (SD), median, and interquartile range (IQR) were computed for the trueness and precision of each ambient color lighting condition and IOS (Table 1). The trueness data had a normal distribution, but the precision data were not normally distributed. The trueness mean values for all subgroups ranged from 19.8 µm to 80.7 µm, while precision median values ranged from 20.8 µm to 75.0 µm. For scans with IOS-1, the trueness mean and

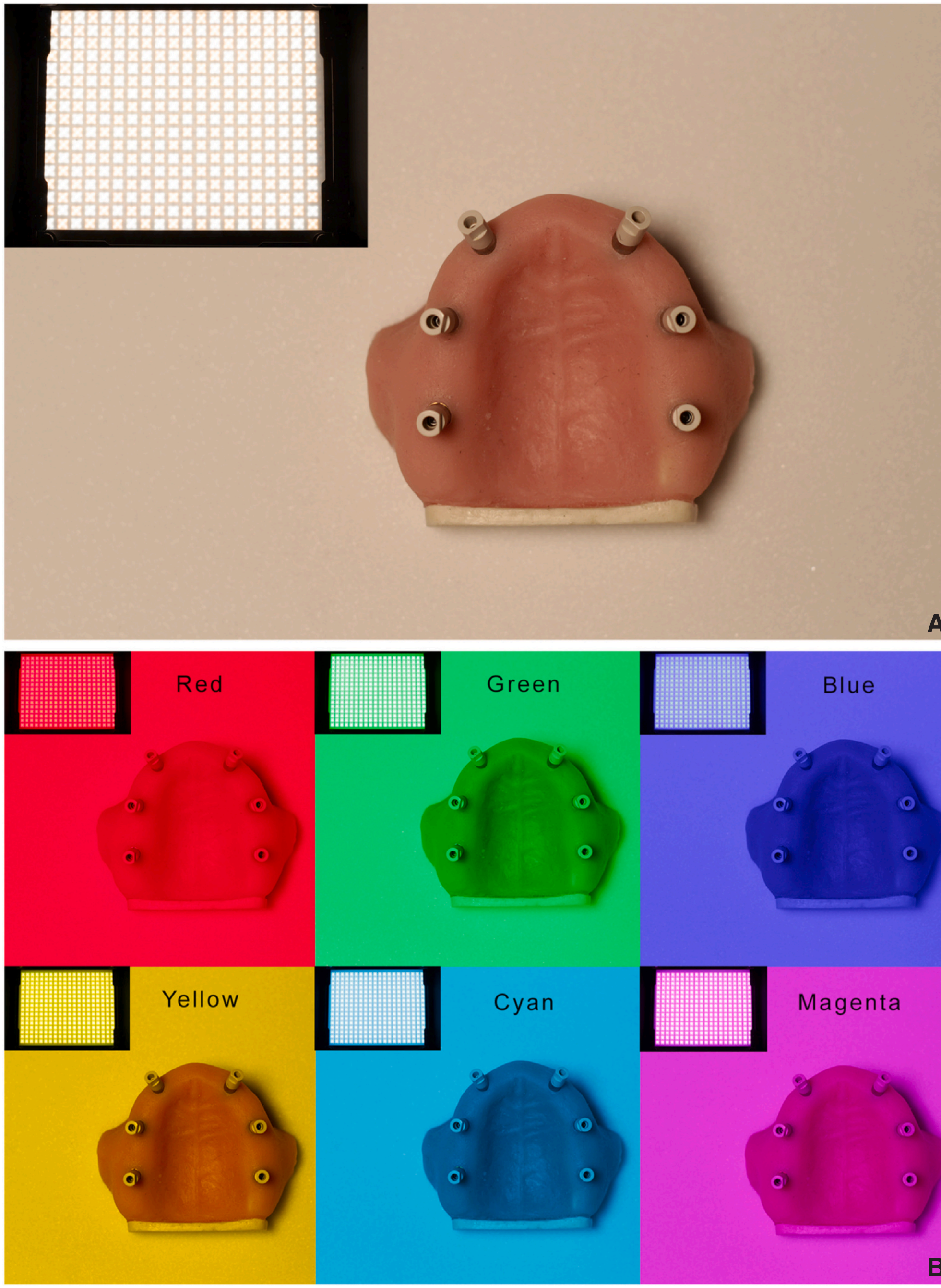

Figure 3. Panel color light configurations for ambient lighting conditions. A, White color. B, red (R), green (G), blue (B), yellow (RG), cyan (GB), and magenta (RB).

precision median values ranged from 19.8 µm (blue group) to 64.3 (cyan group) and from 22.1 µm (blue group) to 60.6 µm (cyan group), respectively. For the IOS-2 scans, the trueness and precision mean values ranged from 51.9 µm (white group) to 80.7 µm (red group) and from 38.6 µm (magenta group) to 75.0 µm (blue group), respectively. The lowest deviation of trueness (mean ±SD) was obtained under blue light with IOS-1 (19.8 ±1.8 µm), and the best precision was found under white light with IOS-1 (20.8 ±7.3 µm). The group IOS-2 had the subgroups with the highest deviation in trueness and precision values (red and blue subgroups, respectively). The results are summarized as boxplot diagrams (Fig. 5).

The analysis of the interaction of IOSs and color ambient lighting conditions with the 2-way ANOVA test could not be performed directly on the original data set because of heteroskedasticity for the trueness and

Figure 4. Color-coded map of pair comparison for trueness with i700 under red ambient lighting.

precision data as indicated by the Levene test (*P*<.05). Consequently, 2-way ANOVA was conducted after aligned rank transformation was performed on the 2 data sets using the aligned rank transform tool.[57] These tests demonstrated a significant interaction effect between factors IOS and ambient color lighting on the trueness and precision values of scans (*P*<.001). Also, both the IOS and ambient color lighting factor presented a significant main effect on trueness and precision data (*P*<.001).

To evaluate the effect of ambient color lighting on the scanning accuracy (trueness and precision) of each IOS, the 1-way Welch ANOVA and Games-Howell test was used for trueness data, and the Kruskal-Wallis and multiple pairwise comparison tests with Bonferroni correction were used for precision data (Table 2). The analysis of different ambient color lighting for each IOS system showed significant differences in the trueness of scans between IOS-1 (*P*<.001) and IOS-2 (*P*=.034). Also, significant differences were obtained in precision for IOS-1 (*P*<.001) and IOS-2 (*P*<.001).

In the IOS-1 group, blue light produced the best trueness mean (19.8 ±1.8 µm) with significant differences from all the other lighting conditions tested (*P*<.001 with yellow, cyan and magenta; *P*=.002 with red; *P*=.021 with green; and *P*=.035 with white). However, under blue light, IOS-1 the precision (22.1 ±13.5 µm) was similar to that under white light (20.8 ±7.3 µm) (*P*=.236). The best accuracy was obtained under blue ambient lighting. The second highest trueness values were obtained under white light (23.6 ±3.6 µm) and green light (31.0 ±9.3 µm), without significant differences between them (*P*=.241). In contrast, the second highest precision values were obtained under red light (28.3 ±16.9 µm) and green light (32.4 ±21.9 µm) (*P*=.667).

In the IOS-2 group, the statistical tests showed significant differences in trueness between red light and white light conditions (*P*=.040); the lowest deviation values were obtained with white light (51.9 ±16.7 µm) and the highest with red light (80.7 ±29.0 µm). The other conditions did not differ significantly in terms of trueness (*P*>.05). Furthermore, white light (63.8 ±24.9 µm) had a similar precision median value with respect to the other light conditions, except for yellow light (52.6 ±24.0 µm) and magenta light (38.6 ±10.4 µm), both of which achieved the highest precision, without significant differences between them (*P*=.073).

Statistical analysis was conducted for each IOS and for each ambient color lighting condition individually. The results demonstrated better scanning accuracy (trueness and precision) for IOS-1 than IOS-2 under all ambient color lighting conditions (*P*<.05), except for both trueness (*P*=.495) and precision (*P*=.436) under cyan light and only for precision under yellow light (*P*=.990).

DISCUSSION

The results of the present study demonstrated significant scanning accuracy discrepancies between the 2 IOSs tested under the same ambient color lighting conditions, and significant differences were found among the 7 ambient color lighting conditions by using the same IOS

Table 1. Trueness and precision (RMS error) for each intraoral scanner and ambient color lighting condition tested (µm)

		Trueness (µm)				Precision (µm)			
Group	**Ambient Light Color**	**Mean**	**SD**	**Median**	**IQR**	**Mean**	**SD**	**Median**	**IQR**
IOS-1 (TRIOS 4; 3Shape A/S)	Red	32.5^{A}	9.3	31.0	16.1	32.0	13.4	28.3^{B}	16.9
	Green	31.0^{AE}	11.0	27.9	15.9	33.7	14.1	32.4^{B}	21.9
	Blue	19.8^{B}	1.8	19.2	3.3	23.6	8.7	22.1^{AB}	13.5
	Yellow	50.2^{C}	12.5	48.5	15.1	50.5	24.7	46.9^{CB}	38.5
	Cyan	64.3^{CD}	27.1	53.4	42.9	62.6	26.6	60.6^{C}	44.4
	Magenta	45.9^{AC}	15.6	44.3	23.0	58.6	23.7	53.2^{C}	34.3
	White	23.6^{E}	3.6	23.6	3.8	20.4	4.9	20.8^{A}	7.3
IOS-2 (i700; Medit)	Red	80.7^{A}	29.0	75.7	51.9	72.5	31.2	62.9^{A}	53.5
	Green	68.1^{AB}	24.8	62.4	34.7	76.5	30.5	68.7^{A}	45.9
	Blue	73.2^{AB}	26.0	60.3	45.1	84.1	35.4	75.0^{A}	51.1
	Yellow	65.25^{AB}	22.4	66.0	24.2	50.4	14.5	52.6^{BC}	24.0
	Cyan	58.8^{AB}	15.0	58.5	21.8	58.9	17.4	58.8^{AB}	22.9
	Magenta	61.2^{AB}	16.6	59.4	21.6	39.2	9.0	38.6^{BC}	10.4
	White	51.9^{B}	16.7	51.9	24.6	67.7	23.7	63.8^{A}	24.9

IOS, intraoral scanner; IQR, interquartile range; SD, standard deviation. Groups with same superscripts (for each IOS within column) not significantly different (*P*>.05) according to post hoc Games-Howell test (trueness) or Bonferroni multiple comparison (precision).

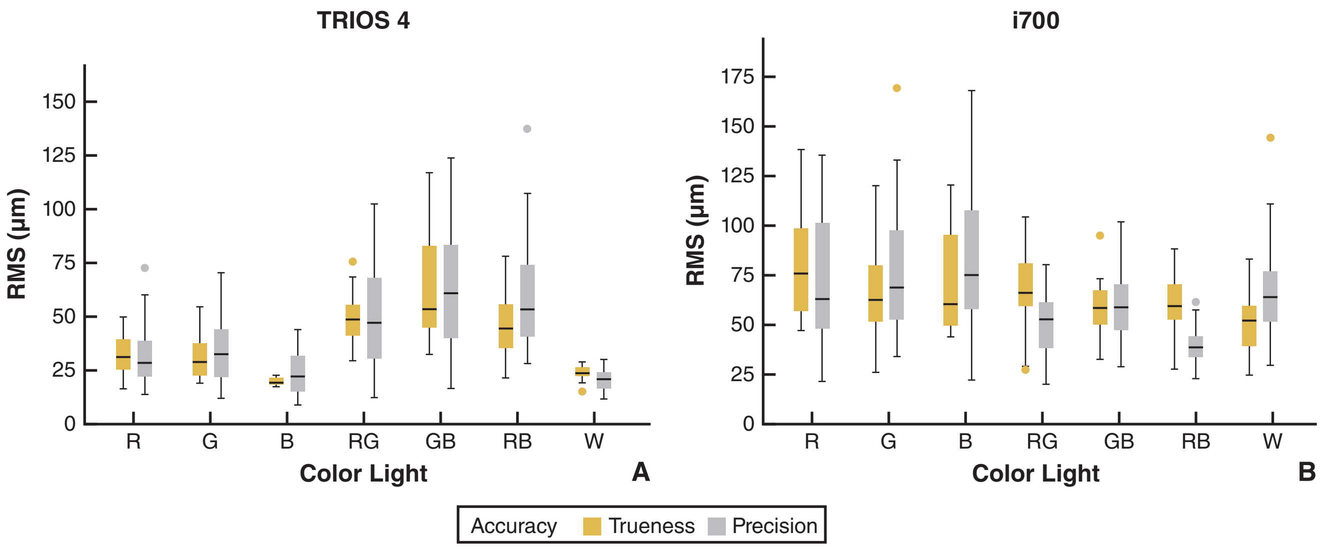

Figure 5. A, Boxplot of accuracy data of TRIOS 4. B, Boxplot of accuracy data of i700. B, blue; G, green; GB, cyan; R, red; RB, magenta; RG, yellow; RMS, root mean square.

Table 2. ANOVA test results for trueness variable between ambient color lighting conditions

Group	df	SS	MS	F	*P*
IOS-1	6	21180.959	3530.160	17.303	<.001
IOS-2	6	8168.412	1361.402	2.795	.015

df, degrees of freedom; F, F-statistic; MS, mean sum of squares; SS, sum of squares

system. Therefore, the null hypotheses that no significant trueness or precision discrepancy would be found among the complete arch implant scans recorded by using the two IOSs tested under the 7 ambient color lighting conditions and that no significant trueness or precision discrepancy would be found among the complete arch implant scans recorded by using the two IOSs tested under the same ambient color were rejected.

Ambient lighting conditions have been previously identified as an important operator-related factor that can reduce the accuracy of IOSs.[24–26,28–32] However, these studies used white ambient light color when assessing the impact of ambient illumination conditions on IOS accuracy.[24–26,28–32] White is the more frequent color temperature of the ambient lighting selected in dental practices, which may explain why these studies selected that specific ambient temperature color. Only 1 previous study[27] assessed the impact of ambient color temperature on the scanning accuracy of one IOS (True Definition; 3M ESPE). Most of the previous studies evaluated ambient lighting conditions in a dentate arch,[24,29,32,33] except for a recent publication[30] that tested scanning complete edentulous arches with implants as in the present study.

Previous studies have shown that the ambient illuminance condition had a significant influence on scanning accuracy and scanning time but that its effect was different depending on the IOS used.[24,27,30] The most suitable single optimal illuminance condition for all IOSs that can maximize the accuracy of scans has not been identified. In the present study, the illuminance level was 1000 lux according to the European Standard for Illumination (EN 12464) standard[58] that recommends 1000 lux for medical or examination rooms.

The authors are unaware of a previous study that considered the color of ambient light as a factor that can influence the accuracy of IOSs; therefore, comparisons with previous studies were not feasible. In the present study, the ambient color lighting condition influenced the scanning accuracy of the IOSs tested differently. The highest accuracy for IOS-1 was obtained under blue ambient lighting (19.8 ±1.8 µm trueness; 22.1 ±13.5 µm precision) and for IOS-2 under magenta ambient lighting (61.2 ±16.6 µm trueness; 38.6 ±10.4 µm precision) and yellow ambient lighting (65.25 ±22.4 µm; 52.6 ±24.0 µm precision).

The mean deviation values of scanning accuracy of the different IOSs under all ambient color lighting conditions were below 100 µm, consistent with the values reported in previous studies,[12,23,30,59] for the clinically acceptable limit value for complete arch scans. However, a consensus of limit deviation values for implant-supported prostheses is lacking.

The methodology used to evaluate the accuracy of IOSs was selected to replicate the actual computer-aided design process, in which the scan body library file was substituted for the mesh. Also, to determine the overall deviation in the scans, a 3D analysis of deviation between scans through the superposition of mesh to obtain the absolute deviation with RMS errors was selected. Therefore, an analysis of the lineal and angular deviation of each implant was not conducted in the present study. Also, the use of scan body library files meant that comparisons were not influenced by the resolution or roughness of each mesh, because the mesh quality of the files compared was identical. Consequently, 3D positional errors of implants occurred, directly related to misfit of the future prosthetic structure.

Limitations of the present investigation included the in vitro environment that did not consider clinical factors on scanning accuracy and the homogeneous ambient lighting conditions, without the variation of illuminance that exists between the anterior and posterior sectors of the oral cavity. Additionally, the assessment of the linear and angular deviations may be more clinically meaningful than the RMS deviations analyzed in the present study. Further studies are recommended to assess the effect of color lighting conditions on the scanning accuracy of additional IOS systems in different clinical scenarios.

CONCLUSIONS

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

1. Ambient color lighting influenced the accuracy of complete arch digital implant scans performed by using either of the 2 IOSs tested.
2. The effect of ambient color lighting was different for each IOS. A universal lighting condition to maximize intraoral scanning accuracy was not found. Therefore, this condition should be specifically selected depending on the IOS system used.

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https://doi.org/10.1016/j.prosdent.2024.03.030