

Impact of color temperature and illuminance of ambient light conditions on the accuracy of complete-arch digital implant scans

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Abstract

Objective: The purpose of the present study was to assess the influence of color temperature and illuminance of ambient light on the accuracy of different intraoral scanners (IOSs) in complete-arch implant scans.

Methods: An edentulous model with six implants and scan bodies was digitized by using a laboratory scanner (DW-7-140; Dental Wings) to obtain a reference mesh. Fifteen scans were performed employing two intraoral scanners (Trios 4;3Shape A/S and i700; Medit Co) at two illuminances (500 and 1000 lux) and three color temperatures (3200, 4400, and 5600K). Scanning accuracy was measured by using a 3D metrology software program (Geomagic Control X). Kruskal–Wallis, one-way ANOVA, and pairwise comparison tests were used to analyze the data ($\alpha = .05$).

Results: Significant differences in trueness and precision values were found among the different IOSs under the same ambient lighting condition and among the different lighting conditions for a given IOS ($p < .05$) except for trueness in i700 groups ($p > .05$).

Conclusions: The influence on the accuracy of color temperature and illuminance varied depending on the intraoral scanner. An optimal ambient scanning light condition was not found; this should be adjusted based on the specific IOS system used. 3200K of ambient light influences the precision of i700 when performed at 1000 lux, decreasing the accuracy. The variation of color temperature at the same illuminance does not affect the scanning accuracy of TRIOS 4, which obtained better accuracy in all scans at 1000 lux.

KEYWORDS

accuracy, ambient conditions, implant prosthesis, intraoral scanner

1 | INTRODUCTION

Intraoral scans are a clinically acceptable alternative to conventional impressions for single-tooth and implant-supported crowns

and short-span fixed dental prostheses (Papaspnyridakos et al., 2014; Rutkūnas et al., 2017; Wulfman et al., 2020; Zhang et al., 2021). However, complete-arch scans using intraoral scanners (IOSs) for fabricating complete-arch tooth- and implant-supported

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rehabilitations have shown contradictory results regarding reliability and accuracy in the literature (Papaspriidakos et al., 2020; Revilla-León et al., 2022; Schmidt et al., 2022; Waldecker, Rues, Awounvo Awounvo, et al., 2022; Waldecker, Rues, Behnisch, et al., 2022; Wulfman et al., 2020). As misfitting prostheses may be related to the increased rate of biological and technical complications, (Abduo & Judge, 2014; Katsoulis et al., 2017; Pan et al., 2021) different techniques have recently been described aiming to increase the scanning accuracy of complete-arch implant digital scans (Gómez-Polo et al., 2020; Kim et al., 2017; Mizumoto et al., 2019, 2020; Paratelli et al., 2021). Many studies have reported mean errors of full-arch digital impressions being $<100\mu\text{m}$. Although a definitive consensus report is lacking, an IOS device should have clinically acceptable values of accuracy, which is usually specified at $100\mu\text{m}$ (Andriessen et al., 2014; Ender & Mehl, 2015; Flügge et al., 2013; Fukazawa et al., 2017; Malik et al., 2018; Mangano et al., 2016; Papaspriidakos et al., 2016; Vandeweghe et al., 2017).

In the literature, multiple factors have been identified that have an impact on the scanning accuracy of IOSs (Abduo & Elseyoufi, 2018; Gimenez-Gonzalez et al., 2017; Revilla-León et al., 2022; Zhang et al., 2021). Among those related to environmental conditions, ambient light illuminance has been recently identified as a predictor factor under different clinical situations in recent studies (Jivanescu et al., 2021; Koseoglu et al., 2021; Ochoa-López et al., 2022; Revilla-León, Jiang, et al., 2020; Revilla-León, Subramanian, et al., 2020, 2021; Wesemann et al., 2020). Discrepancies in scanning accuracies have reported to range between 37% and 44% among different illuminance conditions using the same IOS (Revilla-León, Jiang, et al., 2020; Revilla-León, Subramanian, et al., 2020).

The ambient light conditions have been widely studied for other purposes, such as color shade matching (Revilla-León, Methani, & Özcan, 2021; Wee et al., 2016). It has been reported that light containing the full spectrum of the visible wavelengths in a balanced ratio is equivalent to daylight, with a color temperature of 5500–6000K. This lighting is the most suitable for visual shade selection (Wee et al., 2016). However, there is no consensus on performing the best scanning accuracy of IOSs.

There is a lack of evidence in the current dental literature regarding the influence of color temperature and illuminance of ambient light on the accuracy of IOSs for complete-arch implant scans. A previous study that evaluated these conditions was performed in a dentate arch (Arakida et al., 2018).

The ambient light illuminance condition represents the physical intensity of the total luminous flux on a surface per unit area measured in lux. On the other hand, color temperature light is the temperature (K) at which an ideal black body's radiant energy would evoke the source's color.

Accuracy has been defined by trueness and precision according to ISO 5725-1 (International Organization for Standardization, 1994) Trueness relates to the ability of a scanner to reproduce a dental arch as close to its true form as possible without deformation or distortion. In contrast, precision indicates the degree of identical images acquired by repeated scanning under the same conditions.

The objective of the present study was to assess the impact of temperature color and illuminance ambient light changes on the accuracy of two different IOSs. The null hypotheses were that no significant difference would be found in the accuracy (trueness and precision) of the digital scans among the two different IOSs under the six different ambient lighting conditions assessed and that no significant difference would be found in the scans' accuracy (trueness and precision) under the same ambient light condition among the two IOSs evaluated.

2 | MATERIALS AND METHODS

An edentulous model of a maxilla with silicone artificial gingiva was used (U-007A; Bone Models, Spain). Six dental implants (Ocean IC; Avinent) were placed on the lateral incisors, first premolar, and first molar positions. To simulate the intraoral digital impression for a full-fixed implant prosthesis clinical situation, straight transepithelial abutments (Avinent) and scan bodies of titanium-peek (scan body 2800; Avinent) were placed on (Figure 1).

The maxilla model was digitized using a high accuracy desktop laboratory scanner based on laser light technology (DW-7-140, 7 Series; Dental Wings) to obtain a digital reference model in a standard tessellation language (STL_R) file. The scanner had been previously calibrated following the manufacturer's instructions.

Two intraoral scanners and software versions were evaluated: Trios 4 wireless, version 21.2.2 (3shape A/S), and i700 wireless, version 1.9.1 (Medit). Both scanners had been previously calibrated according to the manufacturer's recommendations.

A restorative dentist (G.O.-L.) with 5 years of experience handling IOSs reordered all digital scans. A 5-min break was taken after every six digital scans completed to avoid operator fatigue. The scanning strategy technique of zigzag was used with two IOSs following previous methodologies (Gómez-Polo et al., 2023; Imburgia et al., 2017; Mangano et al., 2016, 2019, 2020) starting from the right posterior implant scan body to the contralateral side with buccal-to-lingual handpiece movements.

All the digital scans with IOSs were obtained in a room without windows and natural light. The only ambient light source was

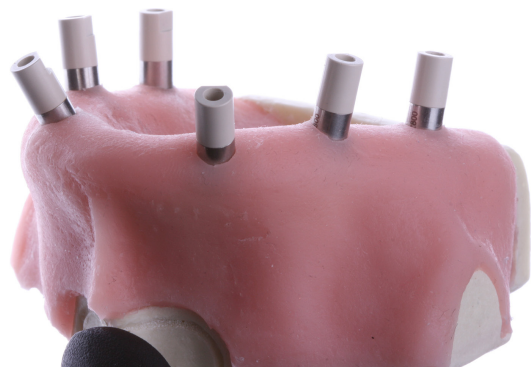


FIGURE 1 Study model with six implant scan bodies.

a light-emitting diode (LED) panel light (660 Pro RGB; Neewer) mounted in a tripod stand. This panel light had cool white and warm white LED beads with adjustable white spectrum color temperature from 3200 to 5600K controlled by an LCD screen or mobile app.

Three-temperature color light (3200, 4400, and 5600K) was evaluated in two different ambient light illuminances at the model (500 and 1000 lux) (Figures 2a–c). The white spectrum color temperature light established on the panel light was checked using a color meter (C-500; Sekonic) and the illuminance with a light meter (LX1330B Light Meter; Dr. Meter Digital Illuminance). Therefore, the present study analyzed the influence on the accuracy of intraoral scans under six ambient lighting conditions, which involved all combinations of the color temperature and illuminance ambient lighting conditions. Based on previous studies, 15 scans were recorded for each group and scanner system.

To replicate the first step of the CAD software process performed by the dental technician, the STL files obtained from each group (reference and experimental) were used to localize implant positions by replacing the corresponding library file on each scan body scanned. Therefore, six superpositions of the scan body library file were performed using best-fit algorithm alignment to create a new STL file of each scan for all groups. These files were employed to calculate the 3D deviations through the best-fit and iterative closest point (ICP) algorithm.

The analysis of accuracy (trueness and precision) was performed with a 3D metrology software program (Geomagic Control X; 3D Systems). To calculate the trueness of each IOS, the meshes with scan bodies library files obtained from each test group were compared with the reference digital model of implant scan body positions. To measure the precision, 10 aleatory records of each group were compared, and the deviations between them were evaluated. The discrepancies identified by software between each mesh pair comparison were shown through a color-coded map. These maps indicated the directionality of the deviation with a color grade scale, inward deviations with cool shades color, outward deviations with warm shade colors, and minimal deviations were colored green (Figure 3). To analyze the data from the 3D deviations, the root mean square (RMS) was calculated to manage absolute errors.

A statistical software program (SPSS Statistics v26; IBM Corp) was used to perform the statistical analysis. The outliers identified were removed from the data set before performing statistical test. The normality of the data set was tested by using the Shapiro–Wilk test. Trueness data were normally distributed ($p > .05$) in contrast to precision values that were not normally distributed ($p < .05$). One-way ANOVA test and Kruskal–Wallis test followed by post-hoc Bonferroni or Games–Howell test were used to analyze the data ($\alpha = .05$).

3 | RESULTS

For scans of TRIOS 4, the trueness and precision mean values ranged from 25.0 μm (4400K–1000 lux) to 42.0 μm (3200K–500 lux) and from 20.4 μm (4400K–1000 lux) to 54.2 μm (5600K–500 lux) respectively. About scans of i700, the trueness and precision mean values ranged from 51.9 μm (4400K–1000 lux) to 79.8 μm (3200K–1000 lux) and from 52.5 μm (5600K–1000 lux) to 108.6 μm (3200K–1000 lux), respectively. The trueness and precision values for each IOS group among the ambient lighting conditions tested are presented in Table 1. Also, the results are summarized as boxplot diagrams (Figures 4 and 5).

To evaluate the interaction of IOSs, color temperature light, and illuminance light conditions, two-way ANOVA was not able to directly perform on the original data set due to the presence of heteroskedasticity analyzed with Levene test for trueness and precision ($p < .05$). For this reason, two-way ANOVA was conducted after aligned rank transformation was performed using the aligned rank transform tool (ARTool). The p value of the interaction term of the IOS and ambient lighting conditions (color temperature and illuminance) in two data sets (trueness and precision) was lower than .05, meaning there was a significant interaction effect among them. Also, the test showed that factors IOS, color temperature, and illuminance conditions in both data sets had significant main effects on trueness and precision ($p < .05$).

The results of the statistical test for trueness and precision revealed significant differences among groups of IOS and ambient lighting condition evaluated ($p < .05$) except for trueness in i700

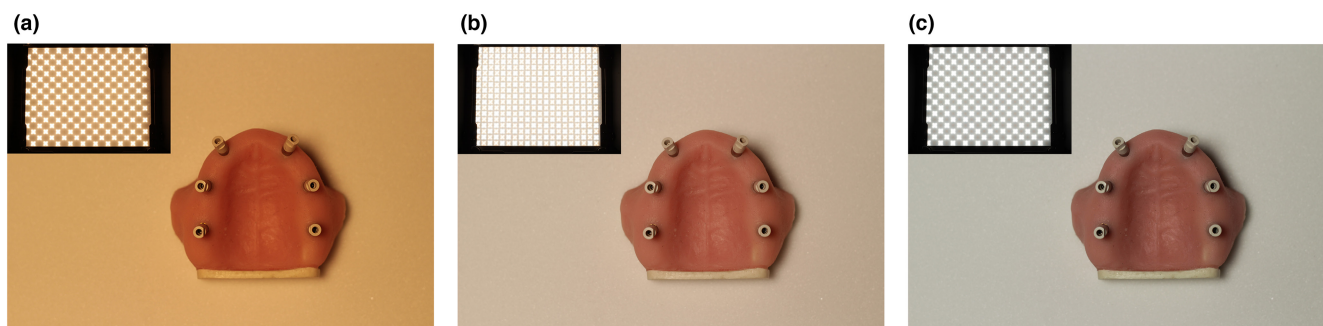


FIGURE 2 (a) Ambient light conditions selected with panel light 3200K. (b) Ambient light conditions selected with panel light 4400K. (c) Ambient light conditions selected with panel light 5600K.

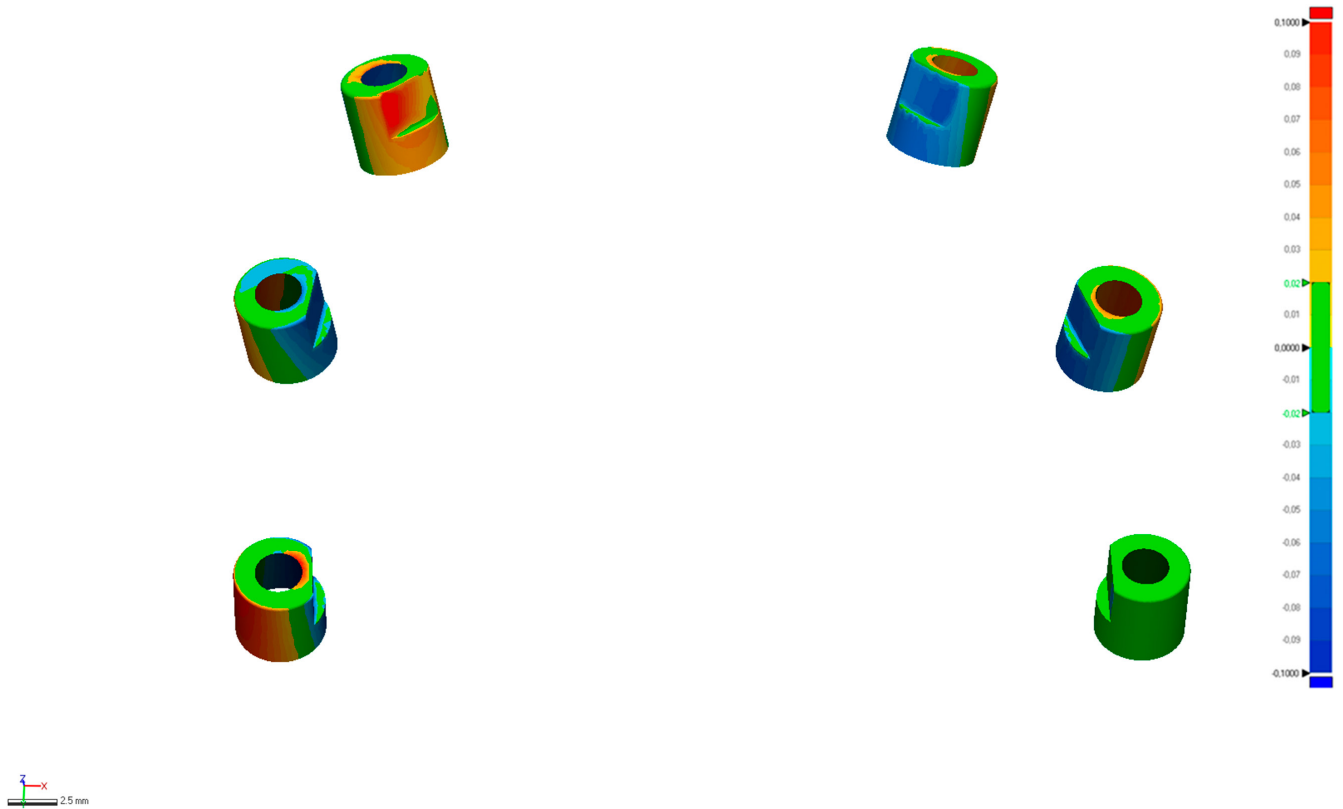


FIGURE 3 Color map of a pair comparison for trueness (Trios 4, 4400K-500lx).

TABLE 1 Trueness and precision (RMS error) for IOSs against ambient lighting condition.

IOS	Lux	Kelvin	Trueness (μm)				Precision (μm)			
			Mean	SD	Median	IQR	Mean	SD	Median	IQR
Trios 4	1000	3200	25.9 ^A	5.4	26.0	8.3	27.0	8.2	25.7 ^A	10.6
		4400	25.0 ^A	3.7	24.3	4.0	20.4	4.9	20.8 ^A	7.3
		5600	25.3 ^A	9.6	26.1	14.5	28.8	12.8	25.4 ^A	17.6
	500	3200	42.0 ^B	9.3	43.9	15.9	47.0	15.9	42.1 ^B	26.6
		4400	39.7 ^B	9.1	39.3	12.1	46.5	11.5	44.0 ^B	15.4
		5600	41.6 ^B	16.8	40.6	25.8	54.2	22.4	50.7 ^B	33.6
i700	1000	3200	79.8 ^A	37.4	68.7	60.4	108.6	49.4	90.7 ^A	72.0
		4400	51.9 ^A	16.7	51.9	24.6	67.7	23.7	63.8 ^B	24.9
		5600	62.4 ^A	28.7	43.4	43.3	55.2	23.4	51.7 ^B	28.7
	500	3200	60.4 ^A	18.1	54.9	22.9	63.2	19.2	63.1 ^B	29.5
		4400	70.0 ^A	24.8	66.2	47.0	65.0	24.5	64.8 ^B	34.0
		5600	68.9 ^A	22.2	68.1	34.5	52.5	18.4	56.1 ^B	31.8

Note: Data provided in microns (μm). 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).

Abbreviations: IOS, intraoral scanner; IQR, interquartile range; SD, standard deviation.

groups ($p > .05$), suggesting that ambient lighting conditions affect each IOS tested differently.

The scanning accuracy (trueness and precision) of ambient light conditions for each IOS was analyzed by pair-wise comparison. The scans of TRIOS 4 under all temperature color light obtained under 1000 lux condition had better trueness and precision than 500 lux

groups ($p < .05$). In the i700 group, there was no significant difference in trueness mean values among ambient lighting conditions. However, a significant difference existed in precision between scans under 3200K and 1000 lux and remaining ambient lighting conditions.

The IOSs achieved different levels of accuracy for taking complete-arch implant impressions under the same ambient lighting

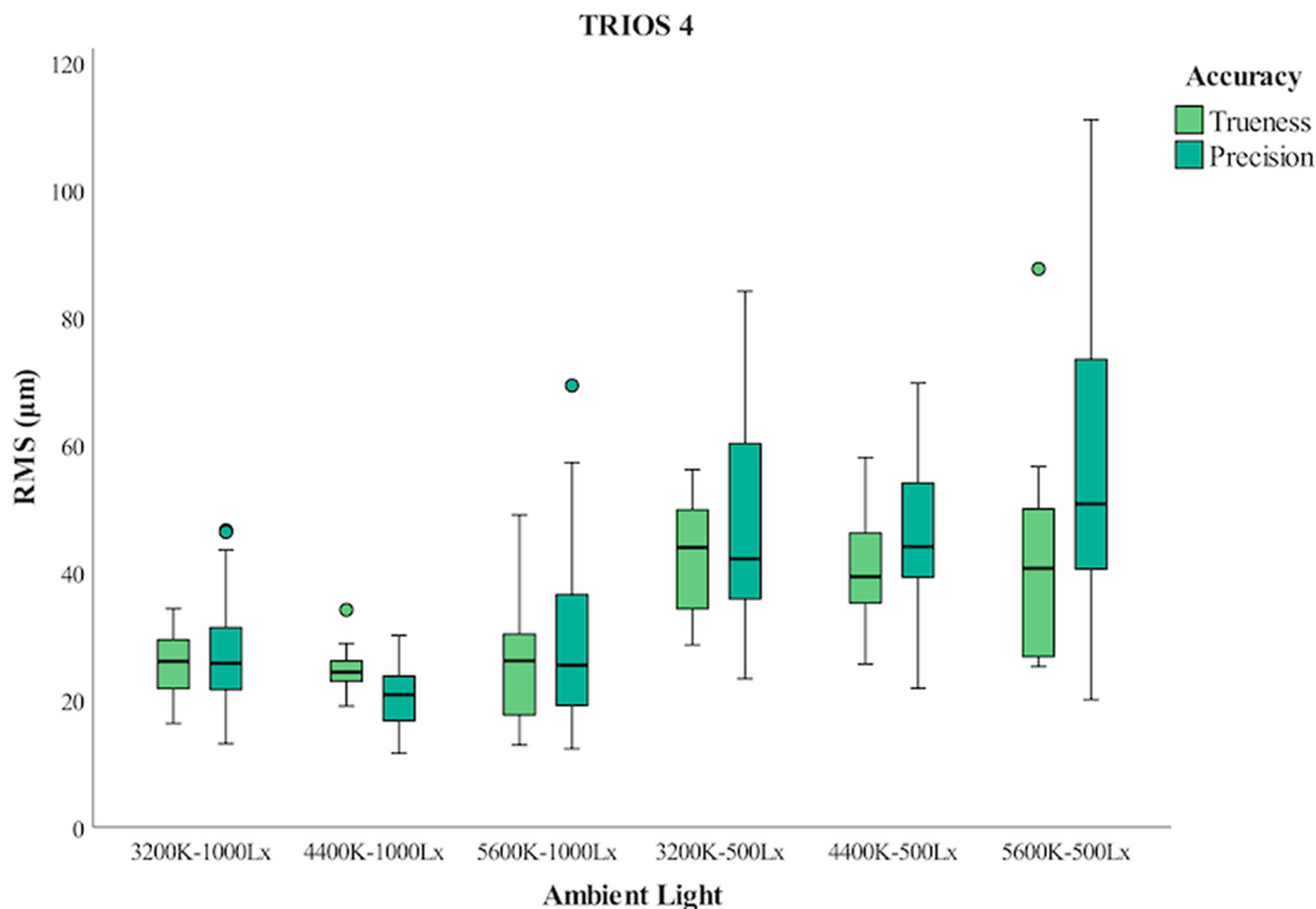


FIGURE 4 Boxplot of scanning accuracy (trueness and precision) of intraoral scanner TRIOS 4.

condition. Trueness values of 5600K-1000 lux and precision values of all lighting conditions were not normally distributed. The Mann-Whitney *U*-test was conducted. For the other groups that were normally distributed, the Student's *t*-test was selected to compare the accuracy between IOS under different lighting conditions individually. All ambient lighting conditions except for precision at 5600K-500 lux had statistically significant differences ($p < .05$). The lower deviation values of scans with TRIOS 4 indicated better accuracy than i700 scans for each ambient lighting condition.

4 | DISCUSSION

Based on the present findings, both null hypotheses were rejected. Significant differences in scanning accuracy were found between the two IOSs tested under the same ambient light conditions, and significant differences were found among the six ambient scanning light conditions while using the same IOS system.

Previous studies analyzed the influence of the ambient lighting conditions on the accuracy of scans performed using different IOSs in dentate (Revilla-León, Jiang, et al., 2020; Revilla-León, Subramanian, et al., 2021, 2020; Wesemann et al., 2020) and edentulous with implants situations (Ochoa-López et al., 2022).

These results revealed that the recommended illuminance condition may vary depending on the IOS system and the purpose of the digital scan performed.

The color temperature of the ambient light evaluated in the previous studies was different. Wesemann et al. (2020) and Ochoa-López et al. (2022) used a light source of 5600K. Revilla-León, Jiang, et al. (2020) employed a white spectrum color temperature light of 4100K. All these studies, evaluated the influence of the illuminance on scanning accuracy, mesh quality, and scanning time, not the color temperature variable of the light.

Studies that analyzed the impact of different color temperatures of ambient light conditions on the accuracy of intraoral scanners are scarce. Arakida et al. (2018) evaluated the influence of the illuminance (0, 500, and 2500 lux) and color temperature (3900, 4100, 7500, and 19,000K) of the lighting on the scanning accuracy of True Definition IOS. They reported that the 500 lux and 3900K obtained the highest accuracy. Still, the numerical values are not comparable with those of the present study as a different technology was used, only two teeth were digitized, and the reference model was an STL file obtained through a CMM machine.

In the present investigation, the color temperature had a different effect on accuracy for each IOS tested. For TRIOS 4, the accuracy is not influenced by color temperature light under the same illuminance condition. However, the scans performed under

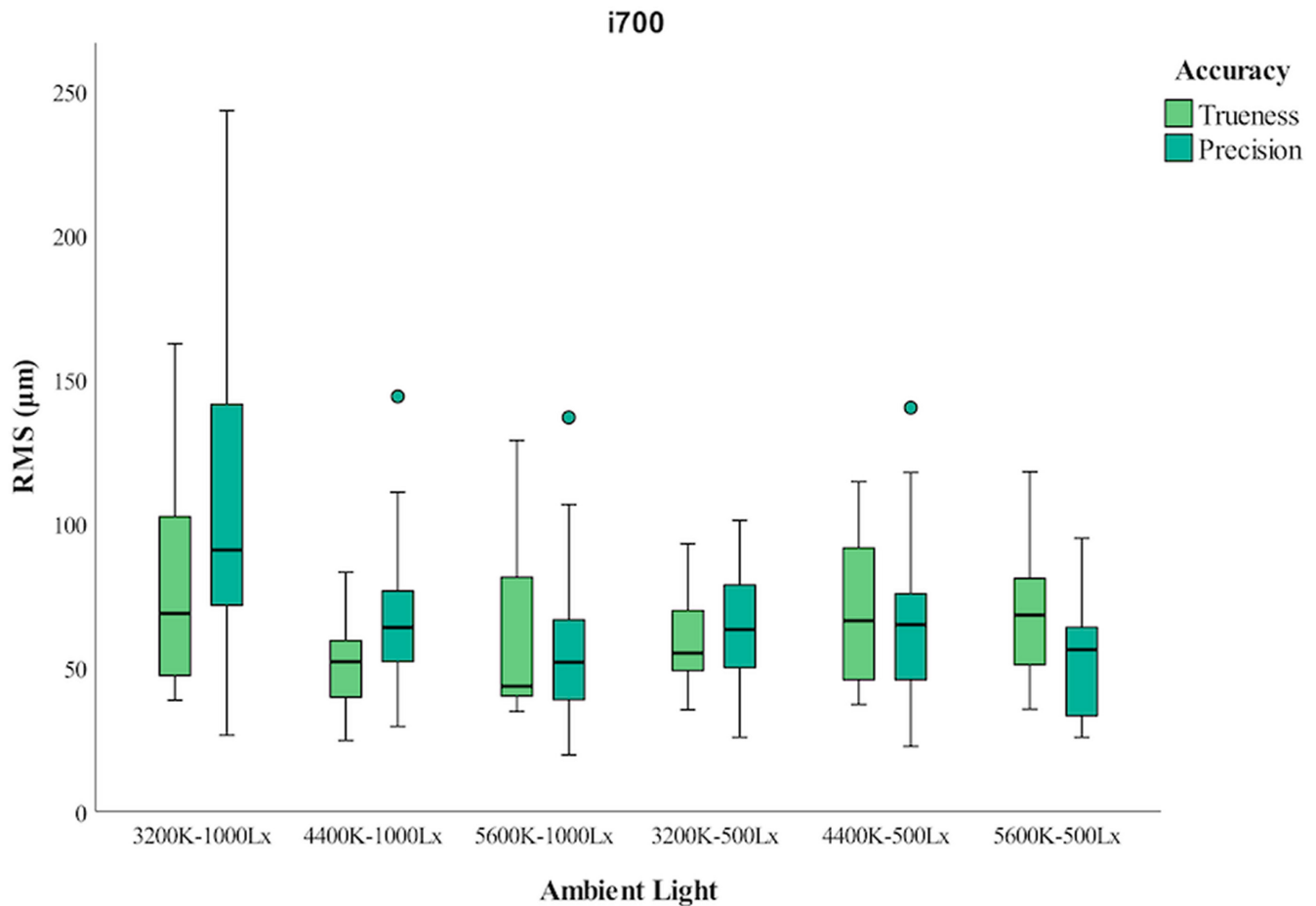


FIGURE 5 Boxplot of scanning accuracy (trueness and precision) of intraoral scanner i700.

1000 lux had higher accuracy than those recorded under 500 lux. For the i700, there is no best ambient lighting condition to obtain higher accuracy scans. Only the 3200K and 1000 lux were identified as the worst condition in terms of precision and, therefore, accuracy.

The deviation means values of accuracy for all groups tested except for 3200K–1000 lux (108.6µm) were below the 100µm acceptability limit (Ender & Mehl, 2015; Fukazawa et al., 2017; Malik et al., 2018), consistent with the values reported in previous studies (Flügge et al., 2013; Mangano et al., 2016, 2020; Vandeweghe et al., 2017). Discrepancies were measured as 3D deviations in scan body library files replacement and, consequently, overall 3D implant positions. The methodology for accuracy analysis employed has the advantage that it is not influenced by the quality or resolution of the mesh and replicates the real CAD process development in digital implant impressions.

Limitations of this study included the in vitro environment that may not have replicated the clinical situation with all influence factors on the accuracy of scans. Additionally, there is a lack of references about the clinical intraoral color temperature and illuminance of ambient light conditions, so further in vivo studies are needed to evaluate the effect of these variables on the scanning accuracy in different clinical scenarios.

5 | CONCLUSIONS

With the limitations of this in vitro study, the following conclusions were drawn:

1. Lighting conditions of color temperature and illuminance influenced the scanning accuracy of IOSs tested for complete-arch implant scans.
2. The influence of color temperature and illuminance on the accuracy of the digital implant scans varied depending on the intraoral scanner. An optimal ambient scanning light condition was not found; this should be adjusted based on the specific IOS system used.
3. For the TRIOS 4 scanner, any color temperature tested at 1000 lux improved the scanning accuracy. For the i700 scanner, the 3200K at 1000 lux decreased the accuracy of scans.

AUTHOR CONTRIBUTIONS

Gastón Ochoa-López conceived the idea, collected the data, performed the analysis, data interpretation, manuscript preparation, and final approval of the manuscript. Marta Revilla-León and Miguel Gómez-Polo contributed to the conception of the study, data interpretation, manuscript preparation, and final approval of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors do not have any financial interests, directly or indirectly, with the products included in the paper.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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