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RESEARCH AND EDUCATION

Do ambient lighting conditions affect the accuracy of implant position capture for complete arch prostheses using intraoral photogrammetry?

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ABSTRACT

Statement of problem. Ambient lighting conditions have been reported to affect the accuracy of intraoral scans. Nevertheless, the influence of these conditions on the accuracy of scans with intraoral photogrammetry (PG) has not been previously analyzed.

Purpose. The purpose of this in vitro study was to assess the influence of light intensity on the accuracy (trueness and precision) of complete arch implant scans captured by using an intraoral PG system and recorded by an intraoral scanner (Aoralscan Elite; Shining 3D), which allowed the recording of both soft tissues and 3-dimensional (3D) implant position.

Material and methods. An edentulous mandibular stone cast with 6 implant abutment analogs was used as the master model. Five groups based on light intensity were determined (100, 500, 1000, 5000, 10 000 lux). Each group was scanned a total of 20 times (n=20), resulting in a total of 100 digital scans (N=100). For the scan acquisition, an IOS including intraoral PG technology (Aoralscan Elite; Shining 3D) was used. Linear and angular deviations were calculated by comparing the digital scans with the reference data from coordinate measuring machine measurements of the master model. (CMM). The Shapiro-Wilk, 1-way ANOVA (Welch), post hoc Tukey, and Levene tests were used to analyze the differences among the groups in terms of trueness and precision (α=.05).

Results. For linear deviations, the lowest deviations in trueness were reported in the group 10 000 lux (0.019 mm), showing statistically significant differences from the groups 100 lux (0.027 mm) (P=.022) and 1000 lux (0.025 mm) (P=.002). For angular deviations, the lowest deviations in trueness were reported for the groups 500 (0.053 degrees), 5000 (0.054 degrees), and 10000 lux (0.046 degrees). Statistically significant differences appeared between these groups (500, 5000, and 10000 lux) and the group 1000 lux (0.086 degrees) (P<.001 in all comparisons), which reported the worst values. No differences in precision were reported for either linear (P=.334) or angular (P=.689) deviations.

Conclusions. Different ambient lighting conditions affected the trueness of the intraoral PG system tested, but not the precision. The magnitude of the differences reported among the groups could be deemed negligible. (J Prosthet Dent 2026;135:819.e1-e6)

Intraoral scanners (IOSs) have shown acceptable accuracy results for the registration of implant-supported single-crown or fixed partial prostheses.[1–4] However, the acquisition of digital scans for complete arch implant-supported prostheses remains a clinical challenge because of the characteristics of the edentulous arch,

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Clinical Implications

Although different ambient lighting conditions affect the trueness of the intraoral photogrammetry system tested in the acquisition of complete arch digital scans, considering the magnitude of the deviations, the clinical significance may be considered minimal.

which results in a decrease in the accuracy of the implant position registration of the digital scans.[5–8] The challenge is caused by operator-related, environmental, and intraoral factors, which condition the accuracy of intraoral digital scans.[9–11] In complete arch intraoral digital scans, factors such as long spans between implants, a lack of anatomic references, or soft tissue mobility complicate the acquisition and processing of digital records made by IOS for complete arch implant-supported prostheses.[12–14] The complication has led clinicians and researchers to design and describe several additional techniques aiming to increase the accuracy in the implant position registration of complete arch scans.[15–21]

Photogrammetry (PG) technologies have been introduced to reproduce the implant position in digital scans.[22–25] While the majority of PG systems incorporate an extraoral camera, a novel system using an intraoral imaging device has recently been introduced.[26] Although previous studies have identified some influencing factors such as scanning distance[27,28] extraoral PG systems have shown reliable accuracy for the digital registration of complete arch prostheses.[29–33] Nevertheless, these PG systems capture the 3-dimensional (3D) position of the dental implants being scanned but do not register soft tissue or teeth, which are essential references when designing a prosthesis. In addition, they suppose an additional acquisition cost.

Recently, an intraoral PG system integrated with an IOS system has been introduced, enabling the registration of both soft tissue and other anatomic structures around implants, as well as the 3D position of the implants (Aoralscan Elite; 3D Shining).[26,34–38] Its software program includes a digital workflow for merging both the soft tissue and the implant position files, resulting in a digital scan with all the necessary elements to design the implant-supported prostheses. The system has been reported in in vitro and clinical studies[34–38] to have an accuracy similar to that of exclusively PG devices. Nevertheless, further studies analyzing the impact of some environmental, operator-related, and intraoral factors are needed.

Ambient lighting conditions have been reported as factors that affect the accuracy of digital scanning with both dental and implant scans.[39–44] Previous studies have assessed the impact of ambient lighting conditions on the accuracy of complete arch digital scans, including light intensity, light temperature, or light color.[45–47] Nevertheless, the authors are unaware of studies on the influence of these conditions on the accuracy of the digital scans obtained by a combined IOS-PG intraoral system.

Accuracy has been divided into trueness and precision as described in the International Organization for Standardization (ISO) 5725 standard.[48] Trueness has been defined as the closeness of agreement between the average of a number of measurements and the true value. Precision refers to the closeness of agreement between repeated measurements, regardless of whether they are close to the true value.[48] The purpose of this in vitro study was to assess the influence of light intensity on the accuracy (trueness and precision) of complete arch implant-supported prosthesis scans captured by using an intraoral PG system (Aoralscan Elite; Shining 3D), which allowed the recording of both soft tissues and 3D implant position. The null hypothesis was that no significant difference in trueness and precision would be found among the complete arch implant scans captured at different light intensities using the intraoral PG system tested.

MATERIAL AND METHODS

An edentulous mandibular stone cast with 6 implant abutment analogs was used as a master model (Multiunit abutment 14007; DESS implants). The cast included pink silicone (Gi-Mask Automix; Coltène) to simulate the soft tissues (Fig. 1). The implant analogs were positioned in the right and left first molar, right and left first premolar, and right and left lateral incisor regions.

Five groups based on light intensity were determined (100, 500, 1000, 5000, 10000 lux).[41,45] Each group was scanned a total of 20 times (n=20), resulting in a total of 100 digital scans (N=100). The sample size was estimated based on previous studies with similar methodologies.[49–51] The ambient lighting conditions were controlled by a digital light meter (LX1330B Light Meter; Dr. Meter Digital Illuminance). The scans were performed in a room without windows, and the light was provided by a light ring (RL-18; Neewer).

Figure 1. Master model with PG scan bodies.

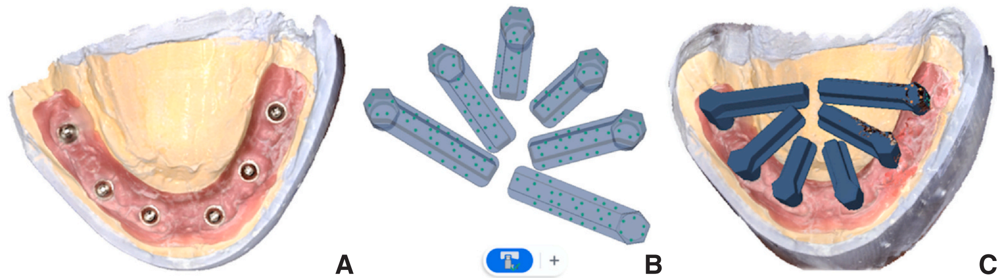

Figure 2. Representative scan sequence procedure. A, Initial standard digital scan of soft tissues. B, Digital scan of PG-ISBs. C, Alignment of soft tissues and PG-ISBs. PG-ISBs, photogrammetry implant scan bodies.

For the scan acquisition, an IOS including intraoral PG technology (Aoralscan Elite v.3.5.6.8; Shining 3D) was used. First, a digital scan of the soft tissues following a zig-zag pattern was recorded using the standard scan mode of the IOS[52–54] (Fig. 2A). The obtained digital scan was duplicated 150 times by using the IOS software program. This step was performed to ensure that all scans started from the same soft tissue pre-scan, considering that it does not influence the subsequently recorded implant position. Then, specially coded calibrated implant scan bodies (ISB) for the intraoral PG technology (Intraoral Photogrammetry Scan Body; Shining 3D) (PG-ISBs) were hand tightened onto the implant analogs at 10 Ncm according to the manufacturer´s recommendations. The PG-ISBs are available in 3 different lengths (long, medium, short) and were placed in the following positions according to their length: long PG-ISB first molars, medium PG-ISB premolars, and short PG-ISB lateral incisors. The PG-ISBs were oriented in the cast so that they were connected in the center without touching each other and remained in the same position during all the digitizing procedures for each group. Subsequently, a complete arch implant scan was recorded by following the scanning pattern recommended by the IOS manufacturer (Fig. 2B). First, a small circle in the center of the arch was made. Then, the distal PG-ISB was scanned, moving from the center of the arch to the body of the PG-ISB, moving above the occlusal surface, and trying to record all the dots included in the PG-ISB surface. Similarly, the remaining PG ISBs were sequentially captured. After capturing the implant position scan, the last step involved aligning the soft tissue and implant position scans by scanning the buccal surfaces of the PG ISBs and implant stone cast from both sides (Fig. 2C). As this registration procedure involves the PG ISBs, it did not require the removal of the ISBs between the recording of the different experimental implant position information scans of this group. Each specimen involving the aligned soft tissue and implant position information scans was exported in STL file format. Each sample was codified with the information of the light intensity (L) and the number of the sample (S) (for example, PG-L100-S1).

The standard tessellation language (STL) files obtained for each group were exported to a dental design software program (exoCAD v.3.2; exoCAD GmbH). A bar connecting all the implants was designed to locate the axis and the geometrical center of each implant (Fig. 3). The resulting STL files were imported into a reverse engineering software program (Geomagic Control X 2024.2.0; 3D systems) to calculate linear distances and angulations of the implants.

The resulting measurements obtained were compared with those acquired from the reference model using a selected coordinate-measuring machine (CMM) (Global Evo; Hexagon Metrology). Euclidean linear and angular deviations were obtained and statistically analyzed (Fig. 4A, B). Accuracy was divided into its 2 components as described in the ISO 5725 standard.[48]

The Shapiro-Wilk test reported statistical significance for both linear and angular deviations (P=.014 for linear deviations; P<.001 for angular deviations), so a violation of the presumption of normality was assumed. The Welch 1-way ANOVA was used to analyze differences among the groups in terms of trueness. The Levene test was used to assess differences among the groups in terms of precision (α=.05).

RESULTS

Descriptive data of linear and angular deviations are summarized in Table 1. For linear deviations, the evaluation of trueness using a 1-way ANOVA revealed statistically significant differences (P=.002) (F=4.91, df1=4, df2=46.5). The post hoc Tukey test revealed that the differences appeared between the group 10 000 lux, with the lower deviations (0.019 mm), and the groups 100 lux (0.027 mm) (P=.022)

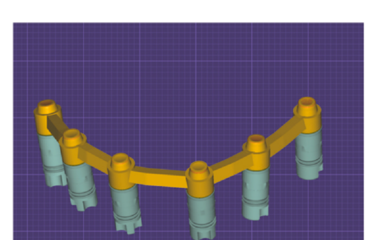

Figure 3. Representative image of virtual bar design connecting implants.

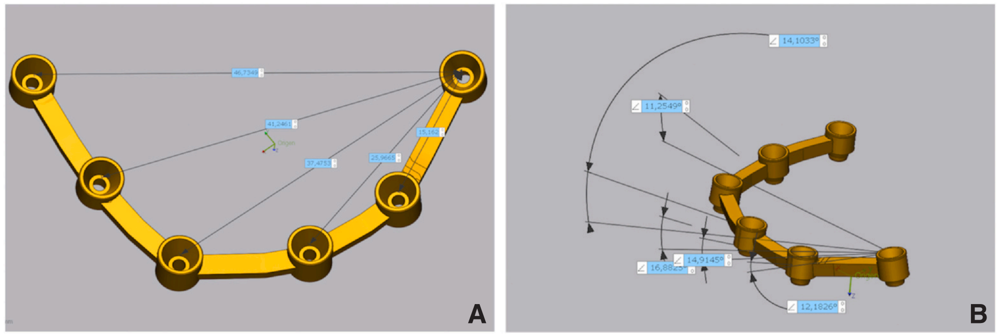

Figure 4. Representative image. A, Euclidean linear measurements. B, Angular measurements.

Table 1. Descriptive data of linear (mm) and angular (degrees) deviations

	Group	N	Mean	Median	Standard Deviation	Interquartile Range	Minimum	Maximum
Linear deviations	100	20	0.027	0.027	0.004	0.0053	0.020	0.034
	500	20	0.023	0.022	0.006	0.0090	0.011	0.032
	1000	20	0.025	0.026	0.008	0.0072	0.013	0.047
	5000	20	0.024	0.023	0.008	0.0081	0.010	0.037
	10000	20	0.019	0.018	0.007	0.0072	0.011	0.042
Angular deviations	100	20	0.070	0.067	0.020	0.015	0.036	0.115
	500	20	0.053	0.048	0.019	0.022	0.024	0.106
	1000	20	0.086	0.09	0.027	0.031	0.048	0.150
	5000	20	0.054	0.052	0.028	0.022	0.025	0.160
	10000	20	0.046	0.043	0.019	0.024	0.024	0.091

and 1000 lux (0.025 mm) (P=.002). The respective mean differences among the groups were 0.008 mm (between 100 lux and 10 000 lux) and 0.006 mm (between1000 lux and 10 000 lux). For the analysis of precision, the Levene test showed no statistically significant differences among the groups (P=.334) (Fig. 5A).

For angular deviations, the evaluation of trueness using a 1-way ANOVA revealed statistically significant differences (P=.001) (F=9.62; df1=4; df2=47.2). The lowest deviations in trueness were reported for the groups 500 (0.053 degrees), 5000 (0.054 degrees), and 10 000 lux (0.046 degrees). The post hoc Tukey test revealed statistically significant differences among these groups (500, 5000, and 10 000 lux) and the group 1000 lux (0.086) (P<.001 for all comparisons) that reported the worst values. Additionally, statistically significant differences were revealed between the groups 10 000 lux (0.046 degrees) and 100 lux (0.070 degrees) (P=.009). For the analysis of precision, the Levene test showed no statistically significant differences among the groups (P=.689) (Fig. 5B).

DISCUSSION

The results of the present study revealed statistically significant discrepancies among the several lighting

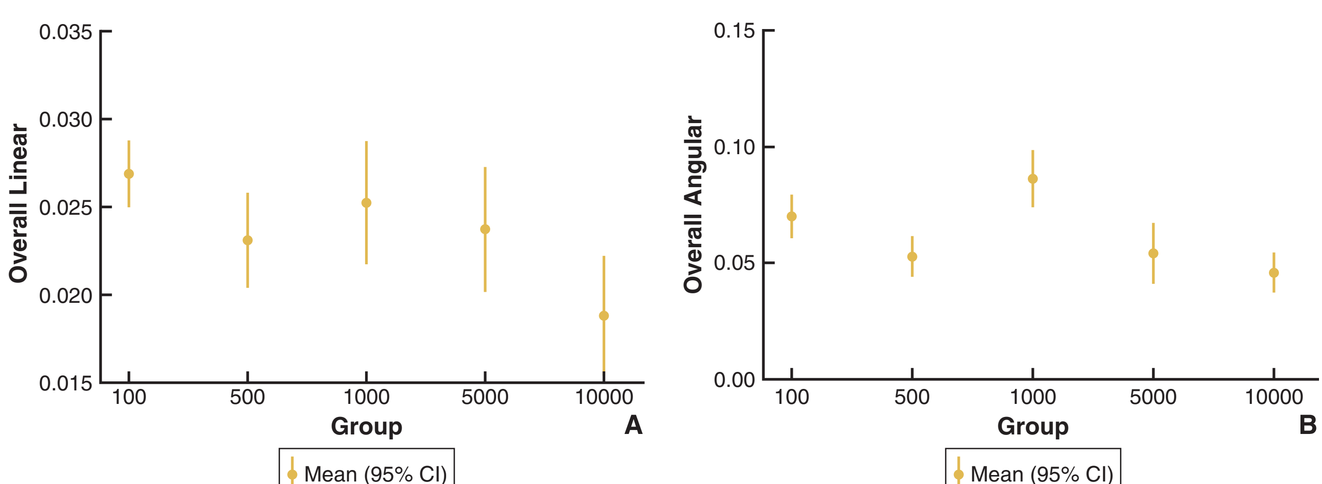

Figure 5. A, Plot of overall linear deviations in comparison with reference data (mm). B, Angular deviations in comparison with reference data (degrees).

conditions evaluated in trueness, but not in precision. Therefore, the null hypothesis that no significant difference in trueness and precision would be found among the complete arch implant scans captured at different light intensities by using the intraoral PG system tested was partially rejected. Nevertheless, the magnitude of the obtained differences was low (up to 8 µm in linear deviations; up to 0.040 degrees in angular deviations), so the impact of the lighting conditions on the accuracy of complete arch implant scans with intraoral PG may be considered clinically irrelevant.[55–57]

Until the recent introduction of intraoral PG systems, the devices used to replicate the implant position in digital scans were either extraoral PG systems or IOSs. Intraoral PG combines features of both systems, as it uses PG technology that is captured by an IOS device. Previous studies have evaluated the impact of the lighting conditions on the accuracy of IOS scanning, in both teeth and implant scans.[39–44] Additionally, prior research studies have analyzed the accuracy of extraoral PG systems.[29–33] Nevertheless, the authors are unaware of studies investigating the influence of ambient light intensity on the accuracy of complete arch implant scans obtained with intraoral PG systems.

Studies on recently introduced intraoral PG systems have described the digital workflow for complete arch rehabilitations[26] or evaluated their accuracy in comparison with IOS or extraoral PG systems.[35–38] Concerning the accuracy of intraoral PG in reproducing implant positions in complete arch prostheses, it has been reported to be better than IOSs and comparable with some extraoral PG systems, although with higher deviations than others.[35–38] Nevertheless, the magnitudes of these deviations were clinically irrelevant, so it has been considered a possible method of registering implant positions for complete arch implant-supported prostheses.[35–38] Additional studies have evaluated the accuracy in the alignment of soft tissues and implant positions, showing similar accuracy for the intraoral PG system evaluated and other methods using IOSs[58] or extraoral PG systems.[34]

As optical devices, the accuracy of the information registered may be conditioned by the ambient lighting conditions, as occurs with IOS systems.[45–47] For implant recording by IOSs, ambient lighting conditions such as light intensity, light temperature, or light color have been identified as influencing factors in digital scan accuracy.[45–47] Their impact has been reported as varying depending on the IOS model, making it relevant in determining the best conditions for each IOS model to optimize the resulting digital scans. Currently, the only commercially available intraoral PG system in dentistry is that used in the present investigation. If additional systems are implemented in the future, the impact of ambient lighting conditions must be evaluated.

Limitations of the present study included the in vitro conditions, angulation, interimplant distances, and the number of implants of the model used. Additional studies are required to further evaluate and compare the results of the present study with other data. Possible further studies may include clinical studies evaluating accuracy using different PG systems, different interimplant distances, and variations in angulation and position of the implants. The results obtained must be carefully extrapolated to different conditions or other PG systems.

CONCLUSIONS

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

1. Different ambient lighting conditions affected the trueness of the intraoral PG system tested, but not the precision.
2. The magnitude of the differences reported among the groups may be considered clinically irrelevant.

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