Journal of Dentistry 142 (2024) 104854

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Impact of scanning distance on the accuracy of a photogrammetry system

Marta Revilla-León [a,b], Miguel Gómez-Polo [c,*], Michael Drone [d], Abdul B. Barmak [e], Clara Guinot-Barona [f], Wael Att [g,h], John C. Kois [i], Jorge Alonso Pérez-Barquero [j]

[a] Graduate Prosthodontics, Department of Restorative Dentistry, School of Dentistry, Faculty & Director of Research and Digital Dentistry, Kois Center, University of Washington, Seattle, WA, United States
[b] Graduate Prosthodontics, Department of Prosthodontics, School of Dental Medicine, Tufts University, Boston, MA, United States
[c] Department of Conservative Dentistry and Prosthodontics, School of Dentistry, Complutense University of Madrid, Pza. Ramón y Cajal s/n., Madrid 28033, Spain
[d] Private Practice, United States
[e] Clinical Research and Biostatistics, Eastman Institute of Oral Health, University of Rochester Medical Center, Rochester, NY, United States
[f] Department of Dental Orthodontics, Faculty of Medicine and Health Sciences, Universidad Católica de Valencia, Valencia, Spain
[g] Founder and Director, The Face Dental Group, Boston, MA, United States
[h] Department of Prosthodontics, University Hospital of Freiburg, Germany
[i] Founder and Director Kois Center, Affiliate Professor, Graduate Prosthodontics, Department of Restorative Dentistry, School of Dentistry, University of Washington, and Private Practice, Seattle, WA, United States
[j] Department of Dental Medicine, Faculty of Medicine and Dentistry, University of Valencia, Valencia, Spain

ARTICLE INFO

Keywords:
Accuracy
Digital impression
Intraoral scanner
Implant scan
Photogrammetry

ABSTRACT

Purpose: To measure the impact of the scanning distance on the accuracy of complete-arch implant scans acquired by using a photogrammetry (PG) system.

Material and methods: An edentulous cast with 6 implant abutment analogs was obtained. A brand new implant scan body was positioned on each implant abutment and digitized using an extraoral scanner (T710; Medit) and the reference file was obtained. Three groups were created based on the scanning distance used to acquire complete-arch implant scans by using a PG (PIC System; PIC Dental): 20 (20 group), 30 (30 group), and 35 cm (35 group). An optical marker (PIC Transfer, HC MUA Metal; PIC Dental) was placed on each implant abutment and a total of thirty scans per group were acquired. Euclidean linear and angular measurements were obtained on the reference file was obtained and used to compare the discrepancies with the same measurements obtained on each experimental scan. One-way ANOVA and Tukey tests were used to analyze trueness. The Levene test was used to analyze the precision values ($\alpha = 0.05$).

Results: Significant linear ($P < .001$) and angular trueness ($P < .001$) discrepancies were found among the groups. For linear trueness, Tukey test showed that the 20 and 30 groups ($P < .001$) and 30 and 35 groups were different ($P < .001$). For angular trueness, the Tukey test revealed that 20 and 30 groups ($P = .003$), 20 and 35 ($P < .001$), and 30 and 35 groups were different ($P < .001$) The Levene test showed no significant linear precision ($P = .197$) and angular discrepancies ($P = .229$) among the groups.

Conclusions: The scanning distance influenced the trueness of complete-arch implant scans obtained with the PG method tested. The maximum linear trueness mean discrepancy among the groups tested was 10 µm and the maximum angular trueness mean discrepancy among the groups tested was 0.02 .

Clinical significance

The optimal scanning distance when acquiring implant scans by using the photogrammetry system tested is 30 cm; however, the linear and angular discrepancy measured with 20- and 35-cm scanning distance was 10 µm and 0.02°, which can be considered of low clinical significance due to the magnitude of the discrepancy measured.

* Corresponding author.
E-mail address: mgomezpo@ucm.es (M. Gómez-Polo).

https://doi.org/10.1016/j.jdent.2024.104854
Received 21 October 2023; Received in revised form 26 December 2023; Accepted 18 January 2024
Available online 19 January 2024

1. Introduction

Photogrammetry (PG) systems can be used to digitally acquire the 3-dimensional (3D) position of dental implants [1–3]; however, these PG systems are unable to capture soft tissue information or digitize adjacent or antagonist dentition [4]. Therefore, an additional impression method is needed, such as an intraoral scanner (IOS).

Currently, there are four dental PG systems available on the market, namely PIC System from PIC Dental, iCam4D from Imetric, Micro-nMapper from ClaroNav, and OXO Fit from OXO [5]. Dental literature has analyzed the accuracy of implant scans obtained by using these PG systems [5–11]. A recent systematic review reported that the PIC system, trueness ranged from 10 to 49 µm and precision ranged from 5 to 65 µm [4]. For the iCam4D system, trueness ranged from 24 to 77 µm and the precision value ranged from 2 to 203 µm [5]. The accuracy of the remaining systems has not been reported yet.

Engineering studies have reported different factors that can impact the accuracy of PG devices for different applications, including resolution of the digital cameras, camara lens distortion coefficients, focal length, number of photographs, targets, shooting distance, percentage of photo overlaps, number of overlapping photos, camera intersection angles, and angles of incidence [12–14]. While dental literature has identified multiple factors that can impact the accuracy of IOSs [15,16], the factors that may influence the scanning accuracy of the dental PG systems for capturing implant positions remains unknown. The purpose of the present *in vitro* study was to assess the influence of the scanning distance (20, 30, and 35 cm) on the accuracy (trueness and precision) of complete-arch implant scans captured by using a photogrammetry system (PIC system; PIC Dental). The null hypotheses were that there would be no significant difference on the trueness and precision among the complete-arch implant scans captured at different scanning distances by using the PG system tested.

2. Material and methods

A maxillary edentulous stone cast with six implant abutment analogs was obtained. The implant abutment analogs (MultiUnit Abutment Plus Replica; Nobel Biocare) were located at the right and left first molar, right and left first premolar, and right and left canine. The maxillary reference cast was positioned into a head mannequin (Adam Patient Simulator; KaVo) aiming to replicate clinical conditions.

For acquiring the refence model, a laboratory scanner (T710; Medit) was used to digitize the cast. A brand new 2-piece PEEK [17,18] implant scan body (ISB) (Scan Abutment Non Engaging, Ø4.8 mm, H10 mm; IPD) was hand-torqued [18,19] on each implant abutment of the cast following the manufacturer's instructions. The scanner was previously calibrated by following the manufacturer's instructions. Then, the cast was digitized by using the selected laboratory scanner following the manufacturer's recommendations. The manufacturer of the selected laboratory scanner reports a scanning accuracy of 4 µm. The reference standard tessellation language (STL) file was exported (Fig. 1). Subsequently, the ISBs were removed from the cast.

A photogrammetry system (PIC System; PIC Dental) was selected to capture consecutive complete-arch implant scans. A specific photogrammetry optical marker (PIC Transfer, HC MUA Metal, Ø4.8 mm; PIC Dental) was hand torqued on each implant abutment of the cast following the manufacturer's recommendations. The optical markers were maintained in the same position during all the digitizing procedures (Fig. 2). The code of each optical marker and its position was introduced into the system program (Table 1). The implant positioned in the maxillary right first molar was marked as the reference implant.

Three groups were created based on the scanning distance used to capture the complete-arch implant scans by using the selected PG system: 20 (20 group), 30 (30 group), and 35 cm (35 group). The scanning distance was standardized by using a measurement tape (Measurement Tape; Bushibu) that was attached to the screw of the tripod (PIXI Mini Tripod; Manfrotto) holding the PG system and the mannequin head. The length of the measurement tape between the tripod and the most anterior surface of the reference cast was determined based on the group tested (20, 30, or 35 cm). The digitizing method involved a Following the ISO 20896-1:2019 [20,21], a sample size of 30 was determined. A total of 30 consecutive PG scans per group were acquired.

The CAD object of the ISB (Scan Abutment Non Engaging, Ø4.8 mm, H10 mm; IPD) was provided by the manufacturer. The reference STL file and the CAD file implant scan body were imported into a reverse

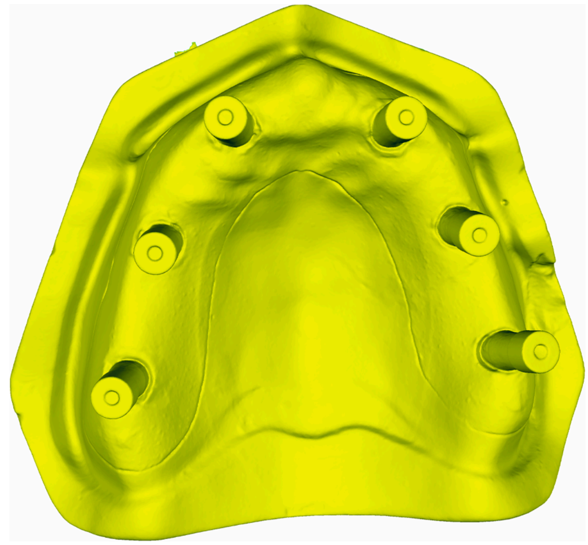

Fig. 1. Digitized reference maxillary stone cast.

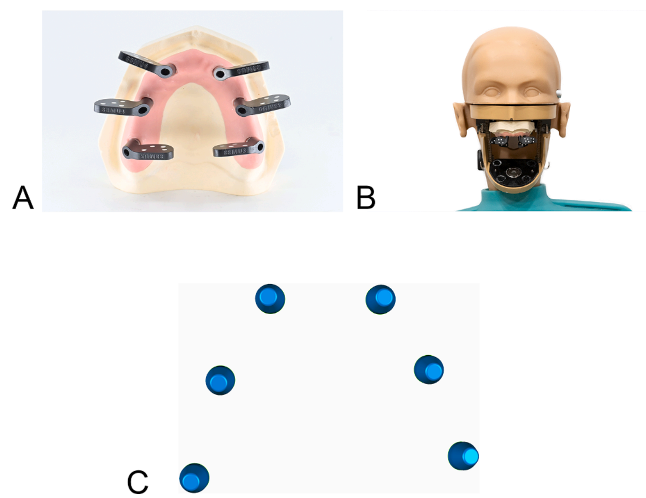

Fig. 2. A, Reference cast with optical markers (PIC Transfer, HC MUA Metal, Ø4.8 mm; PIC Dental) positioned. B, Reference cast positioned in the mannequin head. C, Representative complete-arch implant scan obtained by using the PG system tested. PG, Photogrammetry.

Table 1
Optical marker (PIC Transfer; PIC Dental) codes and positions.

Implant position	Optical marker code
Right first molar	88MUA5
Right first premolar	88MUA4
Right canine	88MUA6
Left canine	88MUA9
Left first premolar	88MUA0
Left first molar	88MUA3

engineering software program (Geomagic, Control X; 3D Systems). In the reference STL, the z plane was located at the most coronal surface of the ISB, follow by the location of the longitudinal axis of the ISB [22]. The z plane marked on the ISB was moved apically 10 mm, which corresponded to the height of the ISB. Afterwards, the point located at the intersection between the z-plane and the longitudinal axis of the implant scan bodies was used to measure the Euclidean linear distances among the 6 implant scan bodies (Fig. 3A–C). Additionally, the longitudinal axes of the implant scan bodies were used to calculate the Euclidean angular distances among the implant scan bodies [22].

Each experimental scan was imported in the same reverse engineering software program. The z plane was located at the apical base of each implant scan abutment, followed by the longitudinal axis of each implant abutment. Similarly, as in the reference file, the point located at the intersection between the z-plane and the longitudinal axis of the implant abutment was used to measure the Euclidean linear distances among the 6 implant abutments (Fig. 3D). Additionally, the longitudinal axes of the implant abutments were used to calculate the Euclidean angular distances among the implant scan bodies [22].

The linear and angular measurements obtained in the reference file were used as a reference to calculate the distortion with the experimental scans. Trueness was defined as the average linear and angular measurement discrepancies between the reference and experimental scans [7–10,20–22]. Precision was described as the linear and angular measurement variations per each group or standard deviation (SD) [7–10,20–22]. The Shapiro-Wilk and Kolmogorov-Smirnov tests revealed that the data were normally distributed ($P < .05$). One-way ANOVA analysis of variance (Fisher's) followed by the pairwise comparison Tukey tests were used to analyze the trueness data. The Levene test was used to compare the variances across the groups and analyze the precision values. All the statistical analysis was completed using a statistical software program (IBM SPSS Statistics for Windows, v26; IBM Corp) ($\alpha = 0.05$).

3. Results

The linear and angular mean ±SD discrepancies obtained among the groups tested are presented on Table 2. Regarding the analysis of the linear measurements, one-way ANOVA (Fisher's) showed significant mean linear measurement discrepancies among the groups tested (df=87, $F = 35.8$, $P < .001$). Additionally, the Tukey post hoc multiple pairwise comparison test showed that 20 and 30 groups ($P < .001$) and 30 and 35 groups were significantly different ($P < .001$) (Fig. 4A). The Levene test showed no significant mean precision discrepancies among the groups tested ($P = .197$) (Fig. 4B).

Table 2
Descriptive statistics of the overall linear and angular measurement discrepancies computed among the groups tested.

Group	Mean ±SD linear measurement discrepancies (μm)	Mean ±SD angular measurement discrepancies (degrees)
20	$25^a \pm 4^a$	$0.15^a \pm 0.01^a$
30	$17^b \pm 4^a$	$0.17^b \pm 0.02^a$
35	$27^a \pm 6^a$	$0.19^c \pm 0.01^a$

SD, standard deviation.

Regarding the analysis of the angular measurements, the one-way ANOVA revealed statistically significant mean trueness differences among the groups tested (df=2, $F = 48.2$, $P < .001$). Additionally, the Tukey post hoc multiple pairwise comparison test showed that 20 and 30 groups ($P = .003$), 20 and 35 ($P < .001$), and 30 and 35 groups were significantly different ($P < .001$). Regarding precision, the Levene test showed no significant mean precision discrepancies among the groups tested ($P = .229$).

4. Discussion

Based on the results from the present investigation, scanning distance impacted the trueness of the complete-arch implant scan captured by using the PG system tested, but no differences were found in the scanning precision. Therefore, the null hypothesis was partially rejected. To the best of the authors knowledge, the present study is the first investigation evaluating the effect of scanning distance on the trueness and precision of a dental PG system. Therefore, comparisons with results reported by previous published studies are not feasible.

Three scanning distances were tested, namely 20, 30, and 35 cm. The scanning distances were selected inside the range at which the PG system was able to capture information. The 30-cm scanning distance obtained the highest linear trueness when compared with the 20- and 35 cm scanning distance. The maximum linear trueness mean discrepancy among the groups tested was 10 μm and the maximum angular trueness

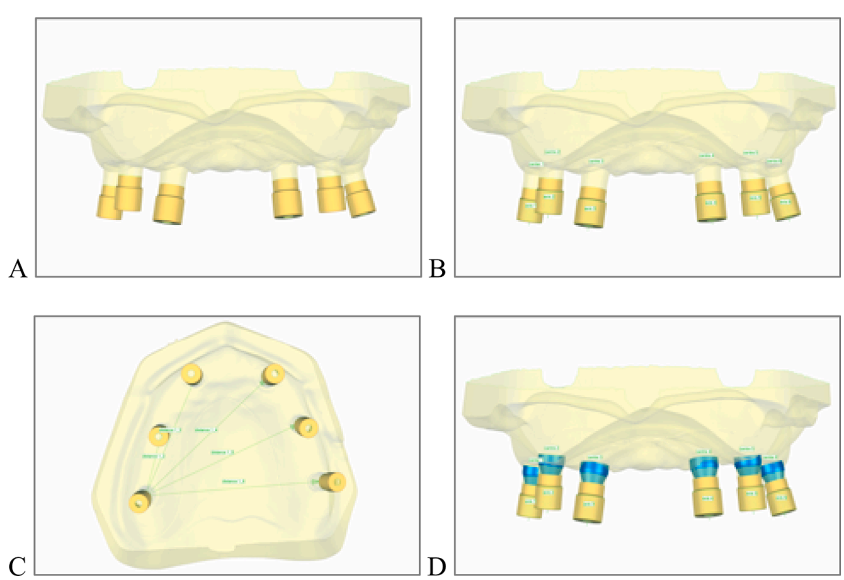

Fig. 3. Measurement method. A, Reference file with the multiple CAD objects of the implant scan body aligned. B, Center point of each of the implant scan body located on the intersection of the longitudinal axis and z-plane. C, Euclidean distances measurements. D, Representative experimental scan alignment with the multiple CAD objects of the implant scan body aligned.

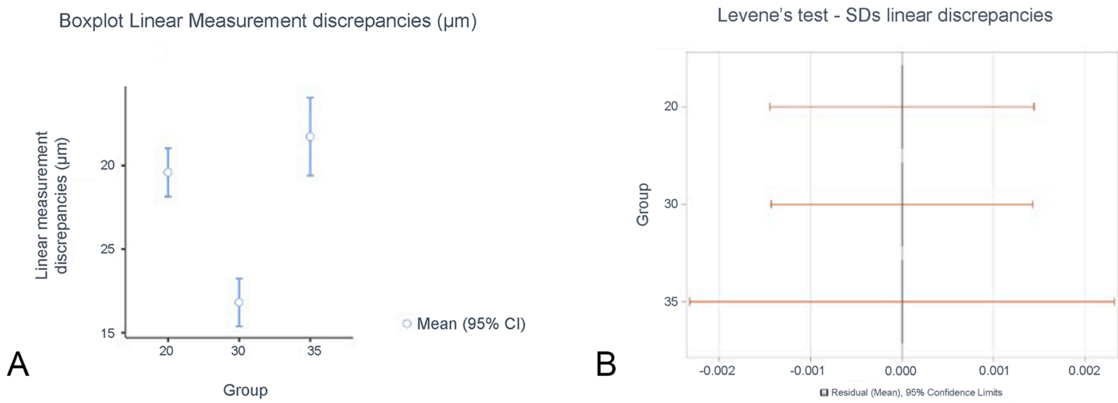

Fig. 4. A, Boxplot of the linear measurement discrepancies measured among the groups tested. B, Boxplot of the angular measurement discrepancies measured among the groups tested.FI.

mean discrepancy among the groups tested was 0.02°. Furthermore, the 30 cm scanning group obtained a linear mean trueness ± precision of 17 ± 4 µm and an angular mean trueness ± precision of 0.17 ± 0.02°. However, the clinical impact of the discrepancy measured is uncertain. Additional studies are needed to assess the impact of the scanning distance and scanning angles on the accuracy of different PG systems recording the 3D position of dental implants with different angulations and positions in the dental arch.

Different digitizing methods have been described in the dental literature for capturing the virtual reference model [5], including a coordinate measurement machine [7,9], industrial scanners [23,24], and laboratory dental scanners [6,8,10]. In the present investigation, an extraoral dental scanner was used to obtain the reference file representing one limitation of the present investigation. However, the same measurement method was used among all the experimental scans. This allowed the direct comparison of the discrepancy values obtained in the different groups tested. Further studies are needed to assess the influence of the scanning distance on the accuracy of the different PG systems. Additionally, Euclidean measurement method used in the present study to analyze trueness and precision has been widely used in dental literature for measuring implant scan accuracy [5,6,10].

Dental literature has reported different vertical displacements of implant scan bodies placed with different torque values [24,25]. In the present investigation, the specific optical markers of the PG system tested were hand torqued in the implant abutment analogs of the reference cast following the manufacturer's recommendations. Additionally, the different material and sterilization methods of implant scan bodies may affect intraoral scanning accuracy [26,27]. Additional studies are needed to assess the impact of the tightening torque value, material, and sterilization methods of optical markers of PG systems on the accuracy of PG technology.

The present study has additional limitations, including the laboratory conditions and the single PG device, the mannequin did not have a facemask, implant abutment design, and implant manufacturer analyzed. Additionally, a single clinical condition involving 6 dental implants in the maxillary arch was considered. Additional laboratory and clinical studies are recommended to further evaluate the influence of the scanning distance on the accuracy of PG systems considering different number and design of implant abutments and PG systems evaluated.

5. Conclusions

Based on the results of the present *in-vitro* study, the following conclusions were drawn:

- The scanning distances tested influenced the trueness of complete-arch implant scans obtained by using the PG method tested. The 30 cm scanning distance obtained the best linear trueness, while the 20-cm scanning distance obtained the best angular trueness.
- The maximum linear trueness mean discrepancy among the groups tested was 10 µm and the maximum angular trueness mean discrepancy among the groups tested was 0.02°. Further studies are needed to assess the clinical impact of the linear and angular discrepancies measured on the fabrication of implant-supported prostheses.

CRediT authorship contribution statement

Marta Revilla-León: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Miguel Gómez-Polo:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Michael Drone:** Project administration, Resources. **Abdul B. Barmak:** Data curation, Formal analysis, Writing – review & editing. **Clara Guinot-Barona:** Data curation, Methodology, Writing – review & editing. **Wael Att:** Conceptualization, Validation, Writing – review & editing. **John C. Kois:** Conceptualization, Project administration, Writing – review & editing. **Jorge Alonso Pérez-Barquero:** Data curation, Methodology, Writing – review & editing.

Declaration of competing interest

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.

References

[1] T. Jemt, T. Bäck, A. Petersson, Photogrammetry–an alternative to conventional impressions in implant dentistry? A clinical pilot study, Int. J. Prosthodont. 12 (1999) 363–368. PMID: 10635208.

[2] D. Peñarrocha-Oltra, R. Agustín-Panadero, L. Bagán, B. Giménez, M. Peñarrocha, Impression of multiple implants using photogrammetry: description of technique and case presentation, Med. Oral Patol. Oral. Cir. Bucal 19 (2014) e366–e371, https://doi.org/10.4317/medoral.19365.

[3] G. Pradíes, A. Ferreiroa, M. Özcan, B. Giménez, F. Martínez-Rus, Using stereophotogrammetric technology for obtaining intraoral digital impressions of implants, J. Am. Dent. Assoc. 145 (2014) 338–344, https://doi.org/10.14219/jada.2013.45.

[4] M. Gómez-Polo, C. Gómez-Polo, J. Del Río, R. Ortega, Stereophotogrammetric impression making for polyoxymethylene, milled immediate partial fixed dental prostheses, J. Prosthet. Dent. 119 (2018) 506–510, https://doi.org/10.1016/j.prosdent.2017.04.029.

[5] M. Gómez-Polo, A.B. Barmak, R. Ortega, V. Rutkunas, J.C. Kois, M. Revilla-León, Accuracy, scanning time, and patient satisfaction of stereophotogrammetry systems for acquiring 3D dental implant positions: a systematic review, J. Prosthodont. (2023), https://doi.org/10.1111/jopr.13751 [Epub ahead of print].

[6] A. Pozzi, P. Carosi, G.O. Gallucci, K. Nagy, A. Nardi, L. Arcuri, Accuracy of complete-arch digital implant impression with intraoral optical scanning and stereophotogrammetry: an *in vivo* prospective comparative study, Clin. Oral Implants. Res. (2023), https://doi.org/10.1111/clr.14141 [Epub ahead of print].

[7] M. Revilla-León, W. Att, M. Özcan, J. Rubenstein, Comparison of conventional, photogrammetry, and intraoral scanning accuracy of complete-arch implant impression procedures evaluated with a coordinate measuring machine, J. Prosthet. Dent. 125 (2021) 470–478, https://doi.org/10.1016/j.prosdent.2020.03.005.

[8] B. Ma, X. Yue, Y. Sun, L. Peng, W. Geng, Accuracy of photogrammetry, intraoral scanning, and conventional impression techniques for complete-arch implant rehabilitation: an *in vitro* comparative study, BMC Oral Health 21 (2021) 636, https://doi.org/10.1186/s12903-021-02005-0.

[9] M. Revilla-León, J. Rubenstein, M.M. Methani, W. Piedra-Cascón, M. Özcan, W. Att, Trueness and precision of complete-arch photogrammetry implant scanning assessed with a coordinate-measuring machine, J. Prosthet. Dent. 129 (2023) 160–165, https://doi.org/10.1016/j.prosdent.2021.05.019.

[10] H. Tohme, G. Lawand, M. Chmielewska, J. Makhzoume, Comparison between stereophotogrammetric, digital, and conventional impression techniques in implant-supported fixed complete arch prostheses: an *in vitro* study, J. Prosthet. Dent. 129 (2023) 354–362, https://doi.org/10.1016/j.prosdent.2021.05.006.

[11] Y.J. Zhang, S.J. Qian, H.C. Lai, J.Y. Shi, Accuracy of photogrammetric imaging versus conventional impressions for complete-arch implant-supported fixed dental prostheses: a comparative clinical study, J. Prosthet. Dent. 130 (2023) 212–218, https://doi.org/10.1016/j.prosdent.2021.09.035.

[12] L.M. Galantucci, G. Percoco, R. Ferrandes, Accuracy issues of digital photogrammetry for 3D digitization of industrial products, Rev. Int. Ing. Numer. 2 (2006) 29–40.

[13] L. Li, X. Zhang, Factors influencing the accuracy of the photogrammetry-based deformation measurement method, Acta Geotech. 14 (2019) 559–574, https://doi.org/10.1007/s11440-018-0663-4.

[14] F. Dai, Y. Feng, R. Hough, Photogrammetric error sources and impacts on modeling and surveying in construction engineering applications, Vis. Eng. 2 (2014) 2, https://doi.org/10.1186/2213-7459-2-2.

[15] M. Revilla-León, D.E. Kois, J.C. Kois, A guide for maximizing the accuracy of intraoral digital scans. Part 1: operator factors, J. Esthet. Restor. Dent. 35 (2023) 230–240, https://doi.org/10.1111/jerd.12985.

[16] M. Revilla-León, D.E. Kois, J.C. Kois, A guide for maximizing the accuracy of intraoral digital scans: part 2-Patient factors, J. Esthet. Restor. Dent. 35 (2023) 241–249, https://doi.org/10.1111/jerd.12993.

[17] M. Revilla-León, A. Lanis, B. Yilmaz, J.C. Kois, G.O. Gallucci, Intraoral digital implant scans: parameters to improve accuracy, J. Prosthodont. (2023), https://doi.org/10.1111/jopr.13749 [Epub ahead of print].

[18] E. Diker, H. Terzioglu, D.N.M. Gouveia, M.B. Donmez, J. Seidt, B. Yilmaz, Effect of material type, torque value, and sterilization on linear displacements of a scan body: an *in vitro* study, Clin. Implant Dent. Relat. Res. 25 (2023) 419–425, https://doi.org/10.1111/cid.13187.

[19] X. Shi, X. Liu, S. Liu, M. Wang, F. Liu, Vertical deviation caused by tightening torque on implant scan body: an *in vitro* study, Int. J. Prosthodont. 35 (2022) 653–659, https://doi.org/10.11607/ijp.7493.

[20] International Organization for Standardization, Dentistry — Digital impression Devices - Part 1: methods for assessing accuracy, ISO 20896-1:2019, International Organization for Standardization, Switzerland, 2019. Available at:https://www.iso.org/standard/69402.html Accessed 02-01-20.

[21] International Organization for Standardization, Accuracy (trueness and precision) of measurement methods and results - Part 1: general principles and definitions, ISO 5725-1: 1994, International Organization for Standardization, Switzerland, 1994. Available at:https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en Accessed 02-01-20.

[22] M. Gómez-Polo, F. Álvarez, R. Ortega, C. Gómez-Polo, A.B. Barmak, J.C. Kois, M. Revilla-León, Influence of the implant scan body bevel location, implant angulation and position on intraoral scanning accuracy: an *in vitro* study, J. Dent. 121 (2022) 104122, https://doi.org/10.1016/j.jdent.2022.104122.

[23] R.J. Pinto, S.A. Casado, K. Chmielewski, J.M. Caramês, D.S. Marques, Accuracy of different digital acquisition methods in complete arch implant-supported prostheses: an *in vitro* study, J. Prosthet. Dent. (2023), https://doi.org/10.1016/j.prosdent.2023.07.008 [Epub ahead of print].

[24] M. Gómez-Polo, M.G. Immorlano, R. Cascos-Sánchez, R. Ortega, A.B. Barmak, J. C. Kois, M. Revilla-León, Influence of the dental arch and number of cutting-off and rescanning mesh holes on the accuracy of implant scans in partially edentulous situations, J. Dent. 137 (2023) 104667, https://doi.org/10.1016/j.jdent.2023.104667.

[25] X. Shi, X. Liu, S. Liu, M. Wang, F. Liu, Vertical deviation caused by tightening torque on implant scan body: an *in vitro* study, Int. J. Prosthodont. 35 (2022) 653–659, https://doi.org/10.11607/ijp.7493.

[26] J. Kim, K. Son, K.B. Lee, Displacement of scan body during screw tightening: a comparative *in vitro* study, J. Adv. Prosthodont. 12 (2020) 307–315, https://doi.org/10.4047/jap.2020.12.5.307.

[27] M. Gómez-Polo, M.B. Donmez, C. Çakmak, B. Yilmaz, M. Revilla-León, Influence of implant scan body design (height, diameter, geometry, material, and retention system) on intraoral scanning accuracy: a systematic review, J. Prosthodont. 32 (2023) 165–180, https://doi.org/10.1111/jopr.13774.