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RESEARCH AND EDUCATION

In vitro comparison between complete arch abutment-level implant impressions with photogrammetry, grammetry, and intraoral scanning

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ABSTRACT

Statement of problem. Photogrammetry (PG) has emerged as a promising recording technique for fabricating implant-supported prostheses. However, the existing evidence on the accuracy of dental PG devices is still limited.

Purpose. The purpose of this in vitro study was to evaluate the trueness and precision of a newly introduced advanced PG device (MicronMapper; SIN 360) by comparing it with grammetry and intraoral scanning.

Material and methods. Four implants (BioHorizons) were placed in an edentulous mandibular model. Multi-unit abutments (BioHorizons) were positioned and tightened to 30 Ncm. A digital reference cast (Control group) was obtained by scanning the model with a laboratory scanner (inEosX5; Dentsply Sirona). Three test groups were evaluated: PS (Primescan), PS-OS (Primescan and OptiSplint), and PG (MicronMapper; SIN 360). Test files were superimposed with the reference file (trueness) and pairwise within groups (precision) using a 3D evaluation software program (Geomagic Control X). Root mean square (RMS) values were calculated. Analysis of variance (ANOVA) was used to analyze differences in RMS values among groups (α=.05), followed by the Tukey post hoc test.

Results. For trueness, group PG showed the lowest mean ±standard deviation RMS values (20.5 ±0.6 µm), followed by PS-OS (30.9 ±16.8 µm) and PS (56 ±0.7 µm). A statistically significant difference was found between groups PG and PS (*P*<.001), as well as PS-OS and PS (*P*=.004). For precision, the lowest RMS values were detected in group PG (6 ±1.2 µm), followed by PS (9.5 ±3.3 µm) and PS-OS (23.3 ±22.3 µm). No statistically significant differences were detected among the test groups in terms of precision (*P*=.192).

Conclusions. Photogrammetry obtained the best accuracy. Grammetry improves the trueness; however, it appears to have no positive impact on the precision of complete arch implant recordings. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Providing highly accurate digital scans for the manufacturing of complete arch implant-supported prostheses still remains a challenge.[1] Multiple factors impact scanning accuracy,[2] including the intraoral scanner (IOS),[3] scanning strategy,[4,5] scan body (SB) design,[6–8] environmental[9–11] and patient-related factors (implant position, inclination, and depth),[12–15] as well as operator experience.[16,17] The most significant accuracy differences have been observed among 4 subgroups: dentate arches, edentulous arches, completely edentulous arches with

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Clinical Implications

Photogrammetry offered better accuracy for complete arch implant recordings, potentially improving the fit and long-term success of implant-supported prostheses. Grammetry enhanced trueness but did not significantly impact precision, suggesting that its benefits may be case-dependent. Clinicians should consider photogrammetry as a valuable digital scanning technique to optimize treatment outcomes, particularly for complete arch prostheses supported by multiple implants, which require high accuracy.

implants, and partially edentulous arches with implants.[18] According to the International Organization of Standardization (ISO) 5725–1 standard,[19] accuracy refers to a relationship between trueness and precision, with trueness being defined as the closeness of measurements to actual values and precision as the reproducibility of measurements. Various methods, including dental floss, acrylic resin, calibrated metal frameworks, and implant supported interim prostheses, have been described for connecting SBs to enhance the accuracy of complete arch implant recordings.[20–23] Although the majority of studies reported the improved performance of splinted recording techniques, the results have still been controversial.[24–28] Furthermore, more time, more scans, and more additional materials, as well as experience in clinical and software related processes, are needed.[20,29] A splinting method that uses a dual-purpose dental implant indexing device (OptiSplint; Digital Arches LLC) has been described.[30,31] This device combines abutment-level SBs and a prefabricated framework that can either be scanned or used to produce a verified stone cast. OptiSplint enables both a fully digital chairside workflow, allowing immediate-load prostheses to be printed in the office (grammetry), and the fabrication of a physical cast for the cementation of Ti-bases or passive fit assessment.[30]

Recent advances in digital photography and specialized software programs have made photogrammetry (PG) a reliable alternative for fabricating implant-supported prostheses.[32,33] PG can improve fit, reduce chairside adjustments, and minimize complications, ultimately leading to more predictable outcomes and sufficient cost benefits.[34] IOSs capture individual images of SBs to generate point clouds and rely on anatomic landmarks for image stitching. In contrast, PG systems use a mathematical technique to determine virtual coordinates by identifying repeated points captured from different angles.[35–37] This method eliminates the need for anatomic landmarks or multiple images, thereby reducing stitching distortions and minimizing the influence of external factors such as ambient light, saliva, or long-span edentulous areas.[38] Although PG systems have been reported to mitigate the limitations of IOSs, studies on the accuracy of PG systems are still scarce, and contradictory results have been reported.[39,40] Previous studies analyzed the accuracy of the PIC system from PIC Dental and iCam4D from Imetric4D.[41] However, new PG devices with improved technologies have been introduced.[40] The aim of this in vitro study was to investigate the accuracy of a recently introduced advanced PG device (MicronMapper; SIN 360) by comparing it with an IOS and grammetry. The null hypothesis was that no statistically significant difference in trueness and precision would be found among complete arch scans captured with different acquisition techniques.

MATERIAL AND METHODS

An edentulous mandibular model with 4 implants (Tapered Internal Plus, 3.5-mm Platform Implant; BioHorizons) located at the right and left lateral incisors and first premolars was used as reference. Three fiducial markers (Arch Tracer; Digital Arches LLC) were placed on the external surface of the mandible at the midline and in the first molar areas. Multi-unit abutments (MUAs) (Internal 3.5-mm multi-unit abutment, straight, non-hexed; BioHorizons) were screwed into the implants and tightened to 30 Ncm by following the manufacturer's guidelines (Fig. 1). Multi-unit SBs (Titanium scan body; BioHorizons) were positioned and hand-tightened on each MUA (Fig. 2), and the reference model was scanned with a high accuracy (2.1 ±2.8 μm)[42] laboratory scanner (inEos X5; Dentsply Sirona). The digital reference cast was exported as a standard tessellation language (STL) file and served as the control (Group Control).

Three different test groups were created (n=5 per group): PS (Primescan, v.SW5.2.10; Dentsply Sirona), PS-OS (Primescan, Splinting with OptiSplint; Digital Arches LLC), and PG (MicronMapper, v.1.3.1; SIN 360)

Figure 1. Edentulous mandibular reference model with 4 implants (Tapered Internal Plus, 3.5 mm Platform Implant, BioHorizons) and multi-unit abutments (Internal 3.5 mm multi-unit abutment, straight, non-hexed, BioHorizons).

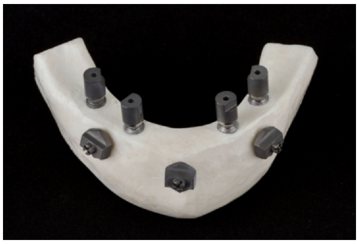

Figure 2. Reference model with multi-unit scan bodies (Titanium scan body; BioHorizons).

Figure 5. Reference model with splinted scan bodies and OptiSplint device.

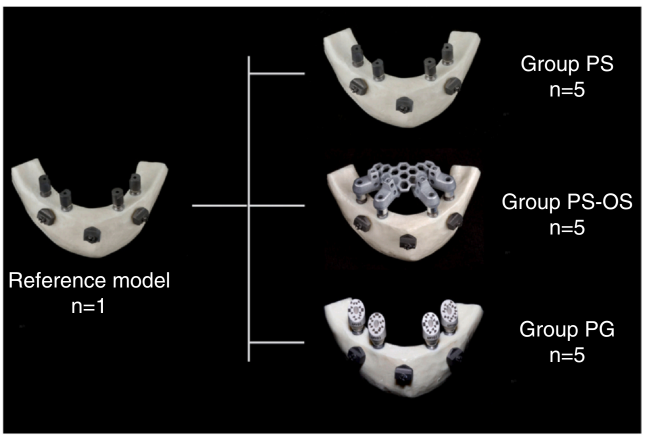

Figure 3. Test setup. PG, Photogrammetry; PS, Primescan; PS-OS, Primescan with Optisplint.

Figure 6. Reference model with optical markers (MicronMapper Scan body, SIN 360).

(Fig. 3). All scans were conducted by a single prosthodontist (L.P.) with more than 10 years of experience using IOSs. In group PS, multi-unit SBs (Titanium scan body; BioHorizons) were positioned and hand-tightened on each MUA (Fig. 2). Scans (Group PS, n=5) were then made (Primescan; Dentsply Sirona) in the same predefined sequence: buccal, occlusal, and lingual. In group PS-OS, SBs (OptiSplint Scan Body; Digital Arches LLC) were seated onto the MUAs and hand-tightened into place. The metal frame (OptiSplint Frame; Digital Arches LLC) was placed and connected to the SBs with a flowable composite resin (Optiweld Dual-cure Composite Material; Digital Arches LLC) (Figs. 4, 5). Scans were made (Primescan; Dentsply Sirona) (Group PS-OS, n=5). In group PG, optical markers (MicronMapper Scan body; SIN 360) were hand-tightened onto the MUAs (Fig. 6), and the PG camera (MicronMapper; SIN 360) (Fig. 7) was used to digitize the reference model by following the manufacturer's instructions (Group PG, n=5).

The scans of all groups were exported as STL-files (Fig. 8). Files were imported into a dental CAD software program (exocad DentalCAD; exocad) to convert different SB designs and orientations into uniform MUAs using a library (BioHorizons) designed for exocad. Afterwards, a 3D evaluation software program (Geomagic Control X; 3D Systems) was used for superimposition. Test files were superimposed with the reference file (trueness) and pairwise within groups (precision) using the best fit algorithm (Fig. 9). Three-dimensional discrepancies between the files were evaluated using the root mean square (RMS) error method.

The sample size calculation with a software program (G*Power version 3.1.9.6; Heinrich-Heine-University Düsseldorf) was based on those of previous studies.[28,43]

Figure 4. Metal frame (OptiSplint Frame; Digital Arches LLC) connected to scan bodies with flowable composite resin (Optiweld Dual-cure Composite Material; Digital Arches LLC).

Figure 7. MicronMapper (SIN 360).

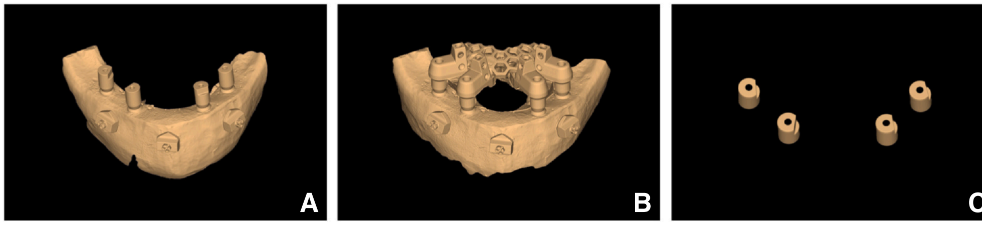

Figure 8. Files obtained from different recording methods. A, Primescan. B, Primescan with OptiSplint. C, MicronMapper.

To detect a moderate to large effect with α=.05 and power=0.8, a minimum of 5 observations per group was required. Statistical analyses were performed using a statistical software program (Prism; Systat Software, Inc). The descriptive data of RMS values (means ±standard deviation [SD]) were calculated for all groups. The Shapiro-Wilk test was used to assess data normality. The Levene test was used to assess homogeneity of variance. Differences in RMS values among groups were analyzed by using analysis of variance (ANOVA) (α=.05). The Tukey test for post hoc comparisons was used to compare groups (α=.05).

RESULTS

The Shapiro-Wilk test indicated that the data followed a normal distribution, while the Levene test suggested that homogeneity of variances could be assumed (P>.05). For trueness, the overall 1-way ANOVA test was statically significant (P<.001). PG showed the lowest mean RMS value (20.5 ±0.6 µm), followed by PS-OS (30.9 ±16.8 µm) and PS (56 ±0.7 µm). A statistically significant difference in RMS values was found between the superimposed control and test files (P<.001). The Tukey post hoc test revealed statistically significant

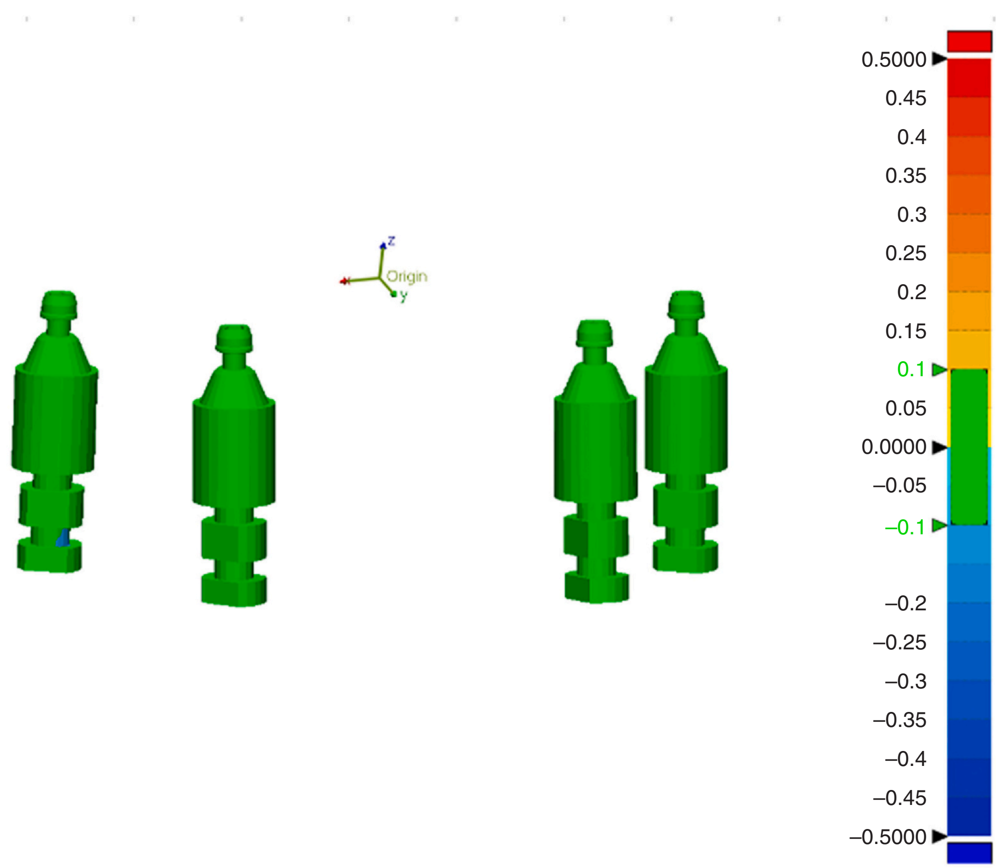

Figure 9. Three-dimensional comparison of standard tessellation language files for trueness of MicronMapper in Geomagic Control X.

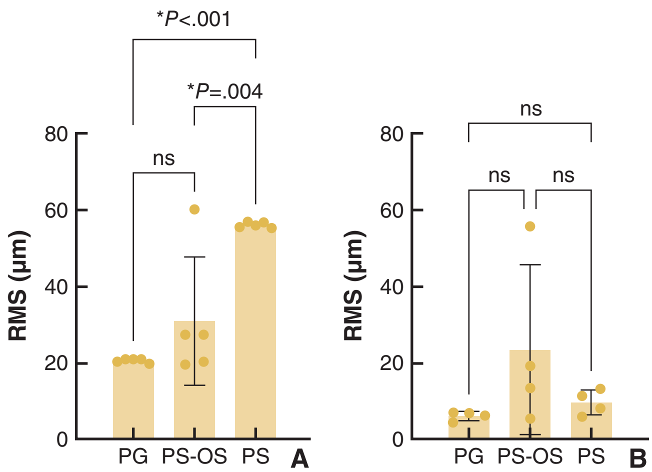

Figure 10. Comparison of RMS values among test groups. A, For trueness. B, For precision. ns, not significant; PG, photogrammetry; PS, Primescan; PS-OS, Primescan with OptiSplint; RMS, root mean square, * indicates significant difference.

differences in RMS values between groups PG and PS (*P*<.001), as well as PS-OS and PS (*P*=.004) (Fig. 10A). For precision, the overall 1-way ANOVA test was not statically significant (*P*=.192). The lowest RMS values were found in group PG (6 ±1.2 µm), followed by PS (9.5 ±3.3 µm) and PS-OS (23.3 ±22.3 µm) (Fig. 10B).

DISCUSSION

The present study was designed to compare the accuracy of digital scans obtained with an advanced PG device with an IOS and grammetry. The null hypothesis that no statistically significant difference in trueness and precision would be found among complete arch scans captured with different acquisition techniques was partly rejected, as statistically significant differences were found between the recording techniques in terms of trueness (PG and PS (*P*<.001), PS-OS and PS (*P*=.004)). However, no statistically significant differences were observed for precision (*P*=.192). PG showed the highest accuracy (trueness and precision) with statistically significant differences in trueness between groups PG and PS (*P*<.001). Grammetry was found to enhance the accuracy in terms of trueness, whereas no significant effect in precision was observed (*P*=.192). The results of the present study align with most of the existing evidence,[8,22,28,32,39] indicating that deviations were lower in digital scans obtained with PG compared with those obtained with IOS. Because of the use of different recording methods and variations in research methodologies, a direct comparison of these studies was difficult.[34] An explanation for the improvement with PG may be that it is less susceptible to imprecision caused by error accumulation when scanning larger areas.[13] Unlike IOSs, which require multiple image stitching, PG systems capture only a few images of special transfers to register implant positions.[14] Furthermore, they have been reported to be less influenced by external or patient-related factors, such as the scanning of edentulous ridges, ambient light conditions, and numbers or angulations of implants.[21,29,35] PG systems used in dentistry use the fundamental principles of PG, but the software program connected to the cameras features specialized algorithms optimized for the oral environment.[13] Previous studies have been investigated 2 different PG devices: PIC camera from PIC Dental[8,15,22,28,29,41] and ICam4D from Imetric4D.[32,33,35,39] The trueness values for the PIC camera ranged from 10 to 49 µm, while for the iCam4D, they ranged from 24 to 77 µm. The precision values for the PIC camera varied between 5 and 65 µm, and for ICam4D between 2 and 203 µm.[34] The newly introduced MicronMapper (SIN 360) incorporates several advancements that enhance the performance, usability, and application scope. The advancements include improved software programs and cameras, advanced algorithms, higher-resolution sensors, multi-object scanning, as well as a more a user-friendly software program interface and ergonomic design.[44] More studies are needed to investigate the difference between PG systems used in dentistry. One clinical study evaluating PG complete arch implant recordings (ICam4D) in 14 participants assessed 90.8% of the distance deviations as clinically acceptable. However, 4 arches (28.6%) still showed unacceptable distance deviations exceeding 150 µm. Another clinical study investigated 5 complete arch implant recordings of the same patient and reported the highest precision for PG imaging (PIC camera), followed by the True Definition and then TRIOS 3.[13] In the present study, PG (MicronMapper) also achieved the highest precision, followed by the unsplinted IOS group (PS) and then the grammetry group (PS-OS). The lower precision of grammetry (PS-OS) may be attributed to a less reproducible scanning path and the larger, more reflective surface area inherent to the OptiSplint device.[17] The authors assume that a scan with reduced framework and adjacent areas may increase the precision of grammetry. This assumption needs to be confirmed in further in vitro studies. MicronMapper, however, may have benefited from being less affected by environmental conditions, such as the glossy surface, and from not relying on a specific scanning pattern.[13] Various methods have been described for connecting scan bodies to enhance the accuracy of complete arch implant recordings, though the results have been controversial.[20] A recently published in vitro study compared digital scans with 3 different splinting techniques: nonconnected SBs, splinted SBs with a printed framework, and splinted SBs with a calibrated metal framework.[22] Consistent with the present findings, the techniques using connected SBs led to higher linear and angular trueness compared with methods that did not. The calibrated metal framework obtained the highest linear and angular trueness, 50% better than the non-calibrated printed framework.[22] However, because of different methodologies, the measurement and evaluation techniques results were not directly comparable. The improved trueness results of connected IOS methods can be attributed to a more precise image stitching, enhanced by capturing well-defined landmarks, as well as the fewer images required.[20,23]

Limitations of the present study included the in vitro design, which cannot completely simulate the clinical conditions, such as the humid environment, mucosal mobility, and limited space. Additionally, only a single PG system was investigated, limiting the generalizability of the findings. Future research should compare PG systems to assess potential differences in accuracy. While PG exhibited the highest accuracy in this study, future research should determine its cost effectiveness, feasibility of implementation in different clinical settings, and the need to train operators to achieve accuracy levels similar to those observed in this study.

CONCLUSIONS

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

1. Photogrammetry was more accurate than intraoral scanning and grammetry for complete arch implant recording methods.
2. Grammetry improved the trueness; however, it appeared to have no positive impact on the precision of complete arch implant recordings.

REFERENCES

1. Prott LS, Graham L, Gierthmuehlen PC, Blatz MB. In-vitro accuracy of digital versus conventional workflows for complete arch implant supported frameworks - A scoping review. *Int J Prosthodont* 2024:1–24.
2. Abduo J, Elseyoufi M. Accuracy of intraoral scanners: A systematic review of influencing factors. *Eur J Prosthodont Restor Dent*. 2018;26:101–121.
3. Amornvit P, Rokaya D, Sanohkan S. Comparison of accuracy of current ten intraoral scanners. *Biomed Res Int*. 2021;2021:2673040.
4. Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. *Int J Comput Dent*. 2013;16:11–21.
5. Latham J, Ludlow M, Mennito A, Kelly A, Evans Z, Renne W. Effect of scan pattern on complete-arch scans with 4 digital scanners. *J Prosthet Dent*. 2020;123:85–95.
6. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: A randomized in vitro trial. *J Prosthodont Res*. 2020;64:128–136.
7. Revilla-León M, Smith Z, Methani MM, Zandinejad A, Özcan M. Influence of scan body design on accuracy of the implant position as transferred to a virtual definitive implant cast. *J Prosthet Dent*. 2021;125:918–923.
8. Tohme H, Lawand G, Chmielewska M, Makhzoume J. Comparison between stereophotogrammetric, digital, and conventional impression techniques in implant-supported fixed complete arch prostheses: An in vitro study. *J Prosthet Dent*. 2023;129:354–362.
9. Agustín-Panadero R, Estada MIC, Alonso Pérez-Barquero J, Zubizarreta-Macho Á, Revilla-León M, Gómez-Polo M. Effect of relative humidity on the accuracy, scanning time, and number of photograms of dentate complete arch intraoral digital scans. *J Prosthet Dent*. 2025;133:865–871.
10. Bayarsaikhan E, Lim JH, Shin SH, et al. Effects of postcuring temperature on the mechanical properties and biocompatibility of three-dimensional printed dental resin material. *Polymers (Basel)*. 2021;13:1180.
11. Revilla-León M, Subramanian SG, Özcan M, Krishnamurthy VR. Clinical study of the influence of ambient light scanning conditions on the accuracy (trueness and precision) of an intraoral scanner. *J Prosthodont*. 2020;29:107–113.
12. Carneiro Pereira AL, Medeiros VR, da Fonte Porto Carreiro A. Influence of implant position on the accuracy of intraoral scanning in fully edentulous arches: A systematic review. *J Prosthet Dent*. 2021;126:749–755.
13. Orejas-Perez J, Gimenez-Gonzalez B, Ortiz-Collado I, Thuissard IJ, Santamaria-Laorden A. In vivo complete-arch implant digital impressions: Comparison of the precision of three optical impression systems. *Int J Environ Res Public Health*. 2022;19:4300.
14. Rutkunas V, Gedrimiene A, Akulauskas M, Fehmer V, Sailer I, Jegelevicius D. In vitro and in vivo accuracy of full-arch digital implant impressions. *Clin Oral Implants Res*. 2021;32:1444–1454.
15. Sallorenzo A, Gómez-Polo M. Comparative study of the accuracy of an implant intraoral scanner and that of a conventional intraoral scanner for complete-arch fixed dental prostheses. *J Prosthet Dent*. 2022;128:1009–1016.
16. Resende CCD, Barbosa TAQ, Moura GF, et al. Influence of operator experience, scanner type, and scan size on 3D scans. *J Prosthet Dent*. 2021;125:294–299.
17. Revilla-León M, Kois DE, Kois JC. A guide for maximizing the accuracy of intraoral digital scans: Part 2-patient factors. *J Esthet Restor Dent*. 2023;35:241–249.
18. Vitai V, Németh A, Sólyom E, et al. Evaluation of the accuracy of intraoral scanners for complete-arch scanning: A systematic review and network meta-analysis. *J Dent*. 2023;137:104636.
19. Beuth Verlag GmbH. Accuracy (trueness and precision) of measuring methods and results. Part I: general principles and definitions. 1994.
20. Paratelli A, Vania S, Gómez-Polo C, Ortega R, Revilla-León M, Gómez-Polo M. Techniques to improve the accuracy of complete arch implant intraoral digital scans: A systematic review. *J Prosthet Dent*. 2023;129:844–854.
21. Zimmermann M, Mehl A, Mormann WH, Reich S. Intraoral scanning systems - A current overview. *Int J Comput Dent*. 2015;18:101–129.
22. Revilla-León M, Barmak AB, Lanis A, Kois JC. Influence of connected and nonconnected calibrated frameworks on the accuracy of complete arch implant scans obtained by using four intraoral scanners, a desktop scanner, and a photogrammetry system. *J Prosthet Dent* 2024.
23. Tallarico M, Lumbau AI, Scrascia R, et al. Feasibility of using a prosthetic-based impression template to improve the trueness and precision of a complete arch digital impression on four and six implants: An in vitro study. *Materials (Basel)*. 2020;13:3543.
24. Denneulin T, Rignon-Bret C, Ravalec G, Tapie L, Bouter D, Wulfman C. Accuracy of complete-arch implant digital scans: Effect of scanning protocol, number of implants, and scan body splinting. *Int J Prosthodont*. 2023;36:219–227.
25. Kernen FR, Recca M, Vach K, Nahles S, Nelson K, Flügge TV. In vitro scanning accuracy using different aids for multiple implants in the edentulous arch. *Clin Oral Implants Res*. 2022;33:1010–1020.
26. Iturrate M, Eguiraun H, Solaberrieta E. Accuracy of digital impressions for implant-supported complete-arch prosthesis, using an auxiliary geometry part-An in vitro study. *Clin Oral Implants Res*. 2019;30:1250–1258.
27. Mizumoto RM, Yilmaz B, McGlumphy Jr. EA, Seidt J, Johnston WM. Accuracy of different digital scanning techniques and scan bodies for complete-arch implant-supported prostheses. *J Prosthet Dent*. 2020;123:96–104.
28. Kosago P, Ungurawasaporn C, Kukiattrakoon B. Comparison of the accuracy between conventional and various digital implant impressions for an implant-supported mandibular complete arch-fixed prosthesis: An in vitro study. *J Prosthodont*. 2023;32:616–624.
29. Revilla-Leon M, Rubenstein J, Methani MM, Piedra-Cascon W, Ozcan M, Att W. Trueness and precision of complete-arch photogrammetry implant scanning assessed with a coordinate-measuring machine. *J Prosthet Dent*. 2023;129:160–165.
30. Crockett RJ, Parikh V, Ahn B, Yao CHD. Use of a dual-purpose implant scan body to obtain both digital and analog records for complete arch fixed implant restorations. *J Prosthet Dent*. 2025;133:36–42.
31. Nagai T, Liu W, Yang CC, Polido WD, Morton D, Lin WS. Intraoral scanning for implant-supported complete-arch fixed dental prostheses (ISCFDPs): Four clinical reports. *J Prosthodont* 2024.
32. Ma B, Yue X, Sun Y, Peng L, Geng W. Accuracy of photogrammetry, intraoral scanning, and conventional impression techniques for complete-arch implant rehabilitation: An in vitro comparative study. *BMC Oral Health*. 2021;21:636.
33. Revilla-León M, Att W, Özcan M, Rubenstein J. Comparison of conventional, photogrammetry, and intraoral scanning accuracy of

complete-arch implant impression procedures evaluated with a coordinate measuring machine. *J Prosthet Dent*. 2021;125:470–478.
34. Gómez-Polo M, Barmak AB, Ortega R, Rutkunas V, Kois JC, Revilla-León M. Accuracy, scanning time, and patient satisfaction of stereophotogrammetry systems for acquiring 3D dental implant positions: A systematic review. *J Prosthodont*. 2023;32:208–224.
35. Zhang YJ, Qian SJ, Lai HC, Shi JY. Accuracy of photogrammetric imaging versus conventional impressions for complete arch implant-supported fixed dental prostheses: A comparative clinical study. *J Prosthet Dent*. 2023;130:212–218.
36. Rivara F, Lumetti S, Calciolari E, Toffoli A, Forlani G, Manfredi E. Photogrammetric method to measure the discrepancy between clinical and software-designed positions of implants. *J Prosthet Dent*. 2016;115:703–711.
37. Stuani VT, Ferreira R, Manfredi GGP, Cardoso MV, Sant'Ana ACP. Photogrammetry as an alternative for acquiring digital dental models: A proof of concept. *Med Hypotheses*. 2019;128:43–49.
38. Pinto RJ, Casado SA, Chmielewski K, Caramês JM, Marques DS. Accuracy of different digital acquisition methods in complete arch implant-supported prostheses: An in vitro study. *J Prosthet Dent*. 2024;132:172–177.
39. Cheng J, Zhang H, Liu H, Li J, Wang HL, Tao X. Accuracy of edentulous full-arch implant impression: An in vitro comparison between conventional impression, intraoral scan with and without splinting, and photogrammetry. *Clin Oral Implants Res*. 2024;35:560–572.
40. Hussein MO. Photogrammetry technology in implant dentistry: A systematic review. *J Prosthet Dent*. 2023;130:318–326.
41. Revilla-León M, Gómez-Polo M, Drone M, et al. Influence of implant reference on the scanning accuracy of complete arch implant scans captured by using a photogrammetry system. *J Prosthet Dent*. 2025;133:252–257.
42. Dentsply Sirona. Dental Lab Scanner InEos X5. 2024. Available from: ⟨https://www.dentsplysirona.com/en-us/discover/discover-by-brand/ineos-x5.html⟩.
43. Conejo J, Yoo TH, Atria PJ, Fraiman H, Blatz MB. In vitro comparative study between complete arch conventional implant impressions and digital implant scans with scannable pick-up impression copings. *J Prosthet Dent*. 2024;131.
44. SIN 360. What is the MicronMapper? 2024. Available at: ⟨https://sin360.us/micronmapper/⟩.

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Lea S. Prott: Investigation, Methodology, Writing – original draft. **Pablo J. Atria**: Formal analysis, Methodology, Software, Writing – review and editing. **Caroline V. Maluf**: Investigation, Software, Writing – review and editing. **Markus B. Blatz**: Supervision, Writing – review and editing. **Julian Conejo**: Conceptualization, Project administration, Supervision, Funding acquisition, Methodology, Writing – review and editing.

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