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RESEARCH AND EDUCATION

Accuracy of impressions for multiple implants: A comparative study of digital and conventional techniques

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ABSTRACT

Statement of problem. Intraoral scanning has benefits over conventional impression making, but whether scanning is sufficiently accurate for multiple implants is unclear.

Purpose. The purpose of this in vitro study was to compare the trueness of digital scans acquired by using intraoral scanners from a small range to a complete arch with the conventional impression technique and to determine the influence of 2 different evaluation methods (best-fit algorithm versus absolute linear deviation) on the outcomes of accuracy assessment.

Material and methods. A mandibular model with 8 implants (A-H) around an edentulous arch was used as the master model. Open-format standard tessellation language (STL) data sets (1 reference file from a highly accurate dental laboratory scanner, 10 files from an intraoral scanner, and 10 files from digitized conventional impressions at room temperature) were imported to a metrology software program, and 5 groups of scanning ranges (AB, FGH, CDEF, BCDEFG, and ABCDEFGH) were identified simulating different clinical situations. Two evaluation methods—root mean square values calculated from the best-fit algorithm and average value of linear discrepancies from absolute linear deviation—were used to describe the trueness values. The impacts of different scanning or impression methods, ranges, and evaluation methods were tested by using a 3-way ANOVA. The effect of the scanning range on accuracy was further identified with 1-way ANOVA. The paired-sample *t* test was used to determine the differences of trueness values between the 2 methods in different groups.

Results. The trueness values of the implant impressions were significantly affected by different scanning or impression methods ($P<.001$), evaluation methods ($P<.001$), and scanning ranges ($P<.001$) as independent variables. With use of the best-fit algorithm, deviations from the digital scans were significantly greater than those from the conventional impressions in cross-arch situations (groups CDEF, BCDEFG, and ABCDEFGH). With use of the absolute linear deviation method, statistically significant lower accuracy was found when larger areas were encountered (groups BCDEFG and ABCDEFGH). Use of the absolute linear deviation method resulted in a higher mean score of inaccuracy than that from the best-fit algorithm method in most situations.

Conclusions. Scanning or impression methods, ranges, and evaluation methods affected the dimensional accuracy (trueness) of scans or impressions with multiple implants. Digital scans had worse trueness values compared with those made with the conventional splinting open-tray technique when cross-arch implant impressions were acquired. (J Prosthet Dent 2022;128:1017-23)

The passive fit of an implant-supported framework is crucial to achieve a successful long-term rehabilitation.[1,2] Misfit of the implant superstructure may induce both mechanical (screw loosening and fracture of implant components) and biologic (marginal bone resorption, peri-implantitis, and osseointegration failure) complications.[3] The accuracy of the implant impression is one of the decisive factors that influence the definitive results.[4]

Traditional implant impression methods include the direct (open-tray) and the indirect (close-tray) techniques. To fabricate a 1-piece framework supported by multiple implants, the open-tray technique is typically used 5 because accurate transfer of the relative locations of the implants is critical.[6] However, the conventional impression is time consuming, operator sensitive, difficult to ship and store, and uncomfortable for the patient.[7] Moreover, errors

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Clinical Implications

When the implants were distributed in cross-arch situations, scanning discrepancies obtained by using the intraoral scanner were much greater than those by the conventional splinted open-tray technique, which implied that the intraoral scanners may not yet be accurate enough for multiple implants with large spans. The best-fit algorithm method can result in a lower discrepancy value compared with that from the absolute linear deviation method.

can be introduced during the entire complex process owing to the inherent properties of the impression and the cast materials.[7]

Intraoral scanners (IOSs) have recently become popular because of their benefits over conventional impression making by directly acquiring digital data from the patient's mouth.[8] Although current evidence suggests a high level of predictability for single-implant scanning,[9] some in vitro studies have reported inconsistent results, with multiple implants with larger spans in the quadrants or in completely edentulous patients.[6,10-12] In some studies, the IOSs had equal or better accuracy than that of conventional methods.[13-18] Other studies reported decreased accuracy as the scanning span increased and concluded that IOSs were contraindicated for multiple implants, especially in edentulous patients.[19-25]

Factors, including the interimplant distance,[26,27] the number of implants,[28] the implant depth and angulation,[29] and the scanner brand,[27,30] have been reported to affect the accuracy of IOSs. In addition, the scanning range[30,31] has been identified as one of the decisive issues. Therefore, a more thorough analysis is required to determine the influence of different scanning ranges with an increased number of implants on the accuracy of IOSs in a variety of simulated clinical situations, from a small edentulous space, to a quadrant, to a complete arch.

The evaluation method is an important factor that directly influences the results of accuracy assessment.[32] Two methods have been used for accuracy assessment: a 3-dimensional superimposition of the standard tessellation language (STL) test files on the reference data sets in accordance with the best-fit algorithm, which allows for an overlap of 2 point clouds by the least squares method, or the absolute linear deviation method, which measures the linear distance of an implant to a certain reference point. The deviation of the distance between the test and the referred data is compared to evaluate the discrepancy. The authors are unaware of comparisons of the best-fit algorithm with the absolute linear deviation methods to assess the accuracy of digital scanning.

Accuracy has been evaluated in terms of trueness and precision, where trueness is defined as the discrepancy between the reference object and the tested object. Precision is evaluated by the random error among the various tests, which reflects the reproducibility of the system.

The aims of the present in vitro study were to compare the trueness of the digital scanners of multiple implants, from a small range to a complete arch, with the trueness of the conventional impression technique and to determine the influence of different evaluation methods (best-fit algorithm with absolute linear deviation) on the outcomes of accuracy assessment. The null hypothesis was that different scanning or impression methods, scanning ranges, and evaluation strategies would not affect the results of accuracy evaluation of multiple implants.

MATERIAL AND METHODS

The present in vitro study compared the trueness of implant scans acquired from an IOS with that of conventional impressions for different ranges and methods. A mandibular acrylic resin model containing 8 straight implants (Camlog screw-line, Ø3.8 mm and Ø4.3 mm; Camlog Biotechnologies AG) was fabricated to simulate clinical situations of equally distributed implants around an arch. The acrylic resin model was duplicated to produce a gypsum cast (Modern Materials, Die-Stone; Kulzer GmbH) with analog implants (Camlog Lab analogs; Camlog Biotechnologies AG) and artificial gingiva (GI-MASK Universal Separator; Coltène), which served as the master model. Eight scan bodies made of polyetheretherketone (PEEK) (Camlog Scanbodies; Camlog Biotechnologies AG) were mounted on the analogs and tightened to 15 Ncm with a wrench. The master model was scanned 3 times for reproducibility (precision) and verified with a highly accurate dental laboratory scanner (3Shape D800 Scanner; 3Shape A/S), and the 3-dimensional data files were exported as STL files, which served as the reference data in this study (Fig. 1).

The master model was then scanned 10 times with the unscrewed scan bodies with an intraoral scanner (3Shape TRIOS Scanner 2; 3Shape A/S). Each scan was started from the most distal right-side scan body and moved to the next until the last one on the left side. The 10 scanned data files were exported as STL files (Fig. 1).

After the digital scan was made, 8 implant-level, open-tray (Camlog Impression posts, open tray; Camlog Biotechnologies AG) impression posts were secured to the analogs with 15 Ncm and splinted together. A polyvinyl siloxane impression material (Silagum-Light and Silagum-MixStar Putty Soft; DMG Medical Devices) was used to make the splinted open-tray impression at room temperature. The model with scan bodies was then

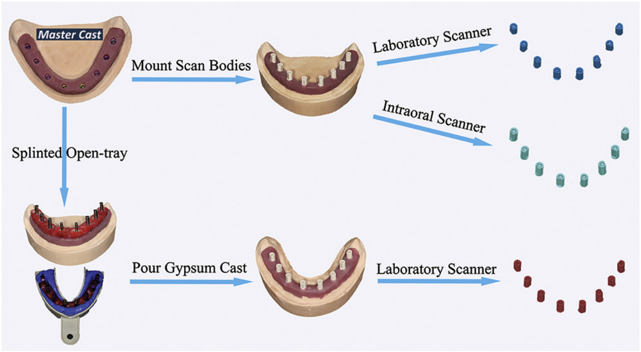

Figure 1. Flowchart of acquiring STL datasets with dental laboratory scanner, digital scan by IOS, and conventional impression. IOS, intraoral scanner; STL, standard tessellation language.

scanned and digitized with a laboratory scanner. The whole process was repeated 10 times, and 10 STL data files were generated (Fig. 1).

All the STL files were imported to a metrology software program (Geomagic Studio 12; 3D Systems). With manual selection of the surface area on the upper horizontal and the curved side surface of the scan body, a horizontal plane and a cylinder were fitted to determine the intersectional point (Fig. 2). With this point and a long axis, a standard cylinder (2-mm radius, 8-mm height) was created with another metrology software program (Rapidform XOR3; Inus Technologies). The cylinder was then cut by the side surface of the scan body to obtain a geometry that simulated the shape of the scan body.

The 8 scan bodies were named A to H from left to right. Five groups with varied implants (AB, FGH, CDEF, BCDEFG, and ABCDEFGH) were identified, simulating different clinical situations (Fig. 3). Four groups were generated by erasing the irrelevant scan bodies and simulated cylinders from the ABCDEFGH group and saved as new files.

Two methods were used to evaluate the accuracy. For the best-fit algorithm, each tested STL file was aligned and superimposed on the reference scan by using the best-fit algorithm method with the tolerance set at 0.001 μm. Color mapping of the discrepancy was displayed for visual inspection, and the root mean square values were calculated from the mean positive and mean negative deviations (Fig. 4). Then, trueness was considered equal to root mean square.

For absolute linear deviation, in each tested STL file, the left-most implant was chosen as the reference. The linear distances between the central points from the other implants to the reference were then calculated. The average value of the linear discrepancies ($\triangle d$) between the test and reference STL files of each cylinder was used to determine the trueness. For example, discrepancies of $\triangle d=|di-di'|$ in the BCDEFG group were averaged as the

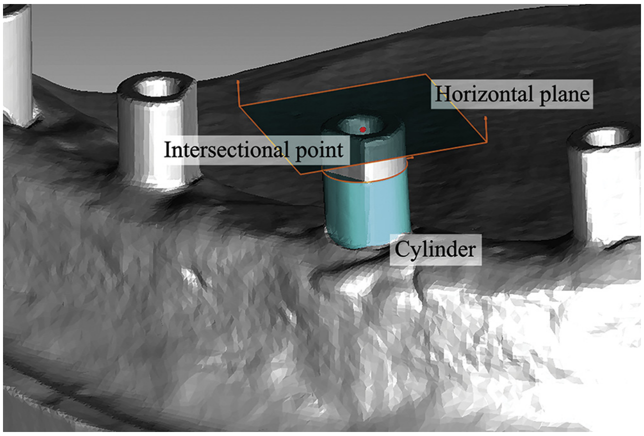

Figure 2. Scan bodies in STL data sets transferred to standard cylinder geometry to facilitate further analysis. STL, standard tessellation language.

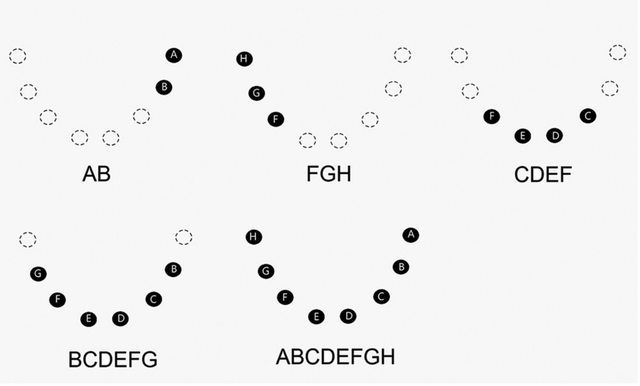

Figure 3. Five groups of scanning ranges and implant numbers simulating different clinical indications.

trueness value (Fig. 5). The trueness was considered as $(\triangle d_1+\triangle d_2+\triangle d_3+\triangle d_4+\triangle d_5)/5$.

The data were analyzed statistically with a software program (IBM SPSS Statistics, v22; IBM Corp) (α=.05). The effect of the scanning or impression methods and ranges, as well as evaluation methods as independent variables, on the dimensional accuracy was first tested by using a 3-way ANOVA. Then, a 1-way ANOVA followed by the Tukey honestly significant difference (HSD) test were used as post hoc multiple comparisons to identify the effect of the scanning range on accuracy. The paired-sample *t* test was used to determine the difference in the trueness values between the 2 methods.

RESULTS

From the 3-way ANOVA, the trueness values of the implant location were significantly affected by different scanning or impression methods (P<.001), evaluation methods (P<.001), and scanning ranges (P<.001) as independent variables. With use of the best-fit algorithm

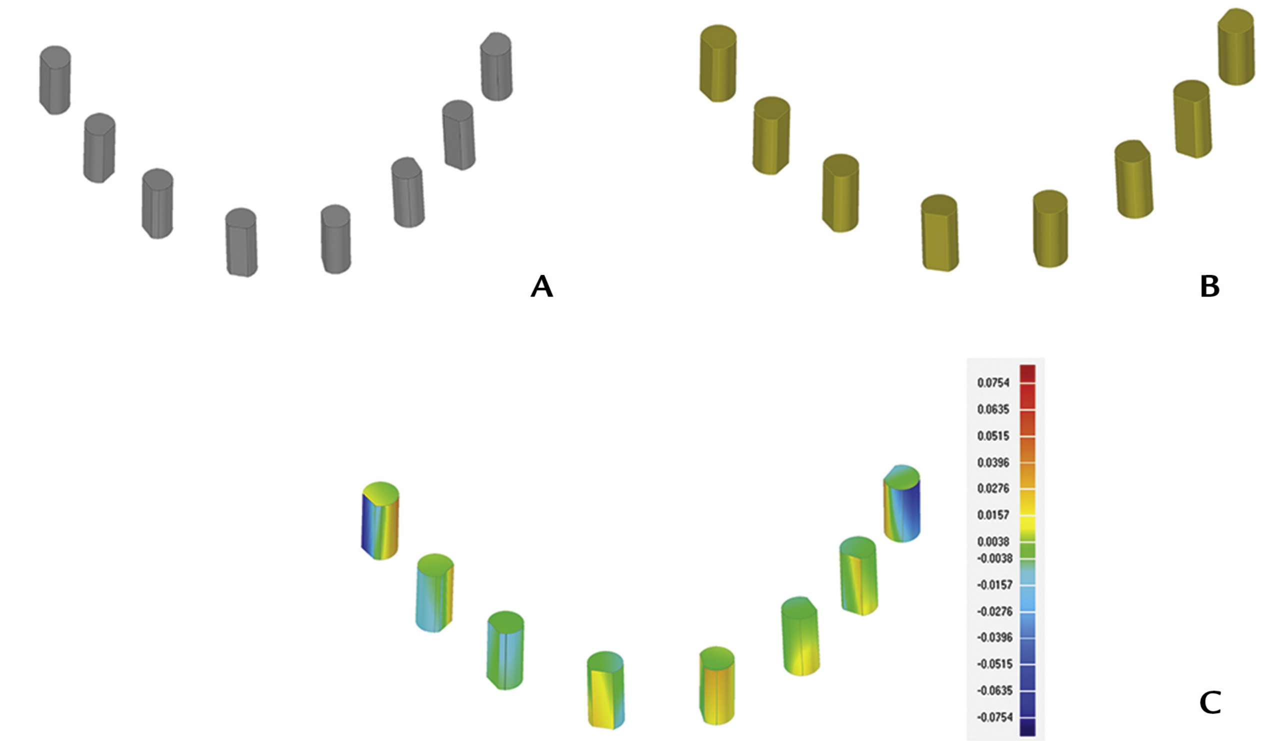

Figure 4. Illustration of best-fit algorithm for trueness evaluation. A, Tested STL file. B, Reference STL file. C, Superimposition and color mapping of discrepancies. STL, standard tessellation language.

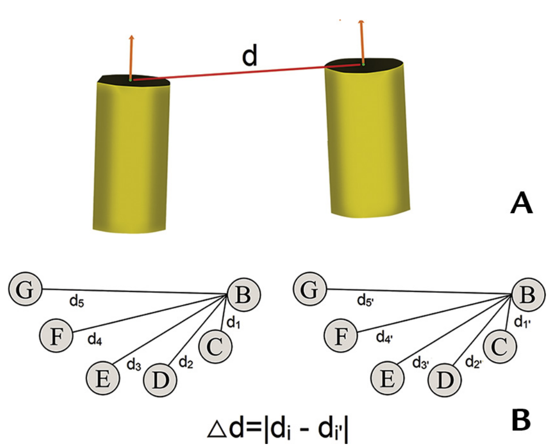

Figure 5. Absolute linear deviation method for trueness evaluation. A, Linear distances of central points of each simulated cylinder to referred simulated cylinder recorded as "d." B, Average value of linear discrepancies ($\triangle$ d) between test (d1 to d5) and reference (d1′ to d5′) STL files of each cylinder in group BCDEFG. d, distances of central points; STL, standard tessellation language.

Table 1. Trueness values (mean ±SD μm) of different scanning range evaluated by best fit algorithm

Scanning Range	Digital Scan	Conventional Impression	*P*
AB	10.4 ±9.2	11.2 ±3.2	.807
FGH	12.9 ±4.1	12.7 ±5.0	.915
CDEF	35.6 ±5.1	17.8 ±4.1	<.001*
BCDEF	53.6 ±11.6	19.0 ±6.1	.007*
ABCDEFG	73.0 ±18.7	24.1 ±12.1	<.001*

SD, standard deviation. **P*<.01.

method, the deviations of both scanning or impression methods increased as the scanning range expanded (*P*<.001 for the digital scan and *P*=.002 for the conventional impression). The implant accuracies within 1 quadrant (groups AB and FGH) showed no statistically significant differences between the digital scan and the conventional impression; however, deviations from the digital scan were significantly greater than those from the conventional impression in cross-arch situations (groups CDEF, BCDEFG, and ABCDEFGH) (Table 1, Fig. 6).

With use of the absolute linear deviation method, the discrepancies increased with an increased scanning range when using the digital scanner (*P*<.001), but no statistically significant differences were found when the conventional impression method was used (*P*=.162). The accuracies of the digital scans were not lower than those of the conventional method in a limited scanning range (groups AB, FGH, and CDEF), but statistically significant lower accuracy was found when a larger area (groups BCDEFG and ABCDEFGH) was encountered (Table 2, Fig. 6).

Deviations calculated by using the best-fit algorithm and the absolute linear deviation were also compared

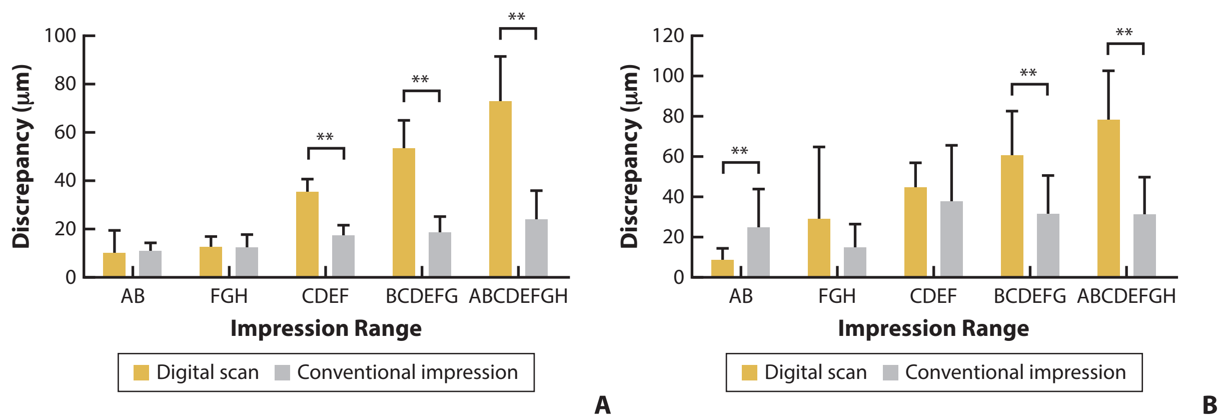

Figure 6. Discrepancies of digital scan and conventional impression in different scanning ranges. A, Evaluated by best-fit algorithm. B, Evaluated by absolute linear deviation method. ** P<.001.

Table 2. Trueness values (mean ±SD μm) of different scanning ranges evaluated by absolute linear deviation

Scanning Range	Digital Scan	Conventional Impression	*P*
AB	8.6 ±6.4	24.8 ±19.3	.027*
FGH	29.0 ±37.6	15.0 ±11.7	.277
CDEF	44.8 ±12.8	37.9 ±27.5	.499
BCDEF	60.8 ±23.0	31.6 ±19.1	<.001*
ABCDEFG	78.2 ±24.5	31.3 ±18.4	<.001*

SD, standard deviation. *P<.05.

Table 3. Comparison of *P* values of trueness between best-fit algorithm and absolute linear deviation methods

	Scanning Range				
P	AB	FGH	CDEF	BCDEF	ABCDEFG
Digital scan	.671	.238	.031*	.117	.219
Conventional impression	.034*	.429	.041*	.023*	.023*

*P<.05.

within each group. In most situations, use of the absolute linear deviation resulted in a higher mean score of inaccuracy than that from the best-fit algorithm, but not all the scores reached statistical significance (Table 3).

DISCUSSION

This study compared the accuracy (trueness) of implant scans over various ranges acquired from an IOS with the conventional method with different evaluation methods. Based on the results, the null hypothesis that the different scanning or impression methods, scanning ranges, and evaluation strategies would not affect the dimensional accuracy of impressions for multiple implants was rejected. The scanning discrepancies obtained by the IOS increased as the scanning range expanded, which had a limited impact on the conventional impression. The digital scan exhibited a lower dimensional accuracy than that of the conventional method when the implants were placed across an arch. The absolute linear deviation method could result in a higher discrepancy value than that of the best-fit algorithm.

Direct digital data acquisition from patients enables clinicians to obtain a 3-dimensional previsualization of the implant position and the surrounding structures, removes material-dependent factors, and increases patient comfort.[13,27,33] The accuracy of the digital scanner has been tested[3,10,31]; however, these results were inconsistent when the digital scanning method was used for a larger scanning range.[12,34,35] Because a digital scan is built by aligning multiple captured images, each alignment can generate an error. Therefore, the more images that are stitched together for long-span impression areas, the greater the error.[30,36] In the present study the scanning range enlarged from 2 adjacent implants to 8 implants, while the conventional splinted open-tray approach was barely affected. This finding was consistent with previous in vitro studies.[33,37]

Based on clinical evidence, the digital scanning method can be a complete substitute for the traditional impression technique when a single implant is scanned.[38] Jiang et al[39] reported on the accuracy of intraoral scanning to fabricate prostheses on adjacent implants within a small scanning range in 31 partially edentulous patients. The average deviation compared with that of the conventional approach was 27.43 μm with the best-fit algorithm method.[39] This was consistent with the discrepancies in groups AB and FGH of the present study in which implants were distributed within quadrants. In 2 other studies, the digital scanning of adjacent implants was compared with the conventional method (no actual prosthesis was fabricated from the digital scan), and the mean ±standard deviation discrepancies were 70.8 ±59 μm[40] and 220 ±30 μm.[21] These inconsistencies in this study may be attributed to differences in the study design, data analysis strategies, or the IOS system.

Inconsistent results have been reported for completely edentulous patients with cross-arch scanning spans. Some authors reported that digital scan had comparable or better accuracy than the conventional approach,[12,15-18] whereas others reported that conventional impressions have better trueness or precision.[21,23-25,37] These inconsistencies may be caused by a different scanning range, the evaluation method, the number of implants, or the IOS brand. In the present study, more discrepancies were found when scanning a complete arch (groups BCDEFG and ABCDEFGH). An average discrepancy of 50 to 80 μm was detected with the digital scan, whereas the conventional impression demonstrated average discrepancy values of 20 to 30 μm.

The clinically relevant threshold for the misfit of implant-supported superstructures has not yet been established, but values ranging from 50 to 150 μm have been proposed.[19,41,42] In the present study, considering the high standard deviation of the differences, the deviations of digital scanning could be clinically significant. Because the screw-retained superstructure on multiple implants requires the highest accuracy, using a digital scan for complete-arch prostheses is not recommended.

Currently, guidelines for the methodological strategy to evaluate the accuracy of multiple implants are lacking. The best-fit algorithm and the absolute linear deviation methods have been the most used. The best-fit algorithm method has been questioned because it averages the distance of the entire surface.[14] The region of deviation visualized in the superimposed image may not be the region of deviation produced by scanning. In clinical practice, because a misfit superstructure cannot be superimposed on the implant, use of the best-fit algorithm might minimize the actual discrepancy values. The absolute linear deviation method seems to avoid such drawbacks because it only calculates the linear differences of the implant to a certain reference without superimposing all the data. However, this approach does not detect the rotational errors of the scanned implant. In the present study, these 2 methods demonstrated the same impression accuracy trends, which were affected by various scanning ranges and different scanning or impression methods. In over half of the digital models, the absolute linear deviation exhibited higher values of discrepancies than those with the best-fit algorithm, which might be explained as the decreased effect of the best-fit algorithm.

Limitations of the present study included its in vitro design, which precludes direct extrapolation of the results to clinical applications. The present study was carried out at room temperature (23 °C) and not mouth temperature (37 °C). Therefore, the thermal contraction of the conventional impression material was not modeled, and a more accurate impression was made than in clinical practice.[43] The data of the different scanning ranges of groups AB, FGH, CDEF, and BCDEFG were extracted from the complete-arch scanning of group ABCDEFGH, which may not accurately replicate the real clinical situation. Whether erasing irrelevant scan bodies form the complete-arch scanning would influence the data accuracy is still unknown. In addition, precision, the other important parameter of accuracy besides trueness, was not evaluated in the study.

CONCLUSIONS

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

1. The scanning or impression method, ranges, and the evaluation method all affected the dimensional accuracy (trueness) of impressions with multiple implants.
2. The digital scans had lower trueness values than those of the conventional splinting open-tray technique when cross-arch implant impressions were acquired.

REFERENCES

1. Taylor TD, Agar JR, Vogiatzi T. Implant prosthodontics: current perspective and future directions. Int J Oral Maxillofac Implants 2000;15:66-75.
2. Moreno A, Gimenez B, Ozcan M, Pradies G. A clinical protocol for intraoral digital impression of screw-retained CAD/CAM framework on multiple implants based on wavefront sampling technology. Implant Dent 2013;22:320-5.
3. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100:285-91.
4. Wee AG, Aquilino SA, Schneider RL. Strategies to achieve fit in implant prosthodontics: a review of the literature. Int J Prosthodont 1999;12:167-78.
5. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004;15:466-73.
6. Naconecy MM, Teixeira ER, Shinkai RS, Frasca LC, Cervieri A. Evaluation of the accuracy of 3 transfer techniques for implant-supported prostheses with multiple abutments. Int J Oral Maxillofac Implants 2004;19:192-8.
7. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res 2013;24:111-5.
8. Nakhaei M, Madani AS, Moraditalab A, Haghi HR. Three-dimensional accuracy of different impression techniques for dental implants. Dent Res J (Isfahan) 2015;12:431-7.
9. Joda T, Bragger U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns. Clin Oral Implants Res 2014;25:1304-6.
10. Stimmelmayr M, Beuer F, Edelhoff D, Guth JF. Implant impression techniques for the edentulous jaw: a summary of three studies. J Prosthodont 2016;25:146-50.
11. Vandeweghe S, Vervack V, Dierens M, De Bruyn H. Accuracy of digital impressions of multiple dental implants: an in vitro study. Clin Oral Implants Res 2017;28:648-53.
12. Menini M, Setti P, Pera F, Pera P, Pesce P. Accuracy of multi-unit implant impression: traditional techniques versus a digital procedure. Clin Oral Investig 2018;22:1253-62.
13. Ender A, Mehl A. Full arch scans: conventional versus digital impressions–an in-vitro study. Int J Comput Dent 2011;14:11-21.
14. Güth JF, Keul C, Stimmelmayr M, Beuer F, Edelhoff D. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig 2013;17:1201-8.
15. Amin S, Weber HP, Finkelman M, El Rafie K, Kudara Y, Papaspyridakos P. Digital vs. conventional full-arch implant impressions: a comparative study. Clin Oral Implants Res 2017;28:1360-7.
16. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res 2016;27:465-72.

17. Pesce P, Pera F, Setti P, Menini M. Precision and accuracy of a digital impression scanner in full-arch implant rehabilitation. Int J Prosthodont 2018;31:171-5.
18. Moura RV, Kojima AN, Saraceni CHC, Bassolli L, Balducci I, Özcan M, et al. Evaluation of the accuracy of conventional and digital impression techniques for implant restorations. J Prosthodont 2019;28:e530-5.
19. Andriessen FS, Rijkens DR, van der Meer WJ, Wismeijer DW. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: a pilot study. J Prosthet Dent 2014;111:186-94.
20. Basaki K, Alkumru H, De Souza G, Finer Y. Accuracy of digital vs conventional implant impression approach: a three-dimensional comparative in vitro analysis. Int J Oral Maxillofac Implants 2017;32:792-9.
21. Alsharbaty MHM, Alikhasi M, Zarrati S, Shamshiri AR. A clinical comparative study of 3-dimensional accuracy between digital and conventional implant impression techniques. J Prosthodont 2019;28:e902-8.
22. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active triangulation technology with blue light for implants: effect of clinically relevant parameters. Implant Dent 2015;24:498-504.
23. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent 2013;109:121-8.
24. Ajioka H, Kihara H, Odaira C, Kobayashi T, Kondo H. Examination of the position accuracy of implant abutments reproduced by intra-oral optical impression. PloS one 2016;11:e0164048.
25. Kuhr F, Schmidt A, Rehmann P, Wöstmann B. A new method for assessing the accuracy of full arch impressions in patients. J Dent 2016;55:68-74.
26. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. Int J Oral Maxillofac Implants 2014;29:853-62.
27. van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of intra-oral dental scanners in the digital workflow of implantology. PloS one 2012;7:e43312.
28. Su TS, Sun J. Comparison of repeatability between intraoral digital scanner and extraoral digital scanner: An in-vitro study. J Prosthodont Res 2015;59:236-42.
29. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. Clin Implant Dent Relat Res 2015;17(Suppl 1):e54-64.
30. Miyoshi K, Tanaka S, Yokoyama S, Sanda M, Baba K. Effects of different types of intraoral scanners and scanning ranges on the precision of digital implant impressions in edentulous maxilla: An in vitro study. Clin Oral Implants Res 2020;31:74-83.
31. Flügge T, van der Meer WJ, Gonzalez BG, Vach K, Wismeijer D, Wang P. The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis. Clin Oral Implants Res 2018;29(Suppl 16):374-92.
32. Baig MR. Accuracy of impressions of multiple implants in the edentulous arch: a systematic review. Int J Oral Maxillofac Implants 2014;29:869-80.
33. Flügge TV, Att W, Metzger MC, Nelson K. Precision of dental implant digitization using intraoral scanners. Int J Prosthodont 2016;29:277-83.
34. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. BMC Oral Health 2017;17:92.
35. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int 2015;46:9-17.
36. Gimenez-Gonzalez B, Hassan B, Özcan M, Pradíes G. An in vitro study of factors influencing the performance of digital intraoral impressions operating on active wavefront sampling technology with multiple implants in the edentulous maxilla. J Prosthodont 2017;26:650-5.
37. Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent 2016;115:313-20.
38. Abdel-Azim T, Zandinejad A, Elathamna E, Lin W, Morton D. The influence of digital fabrication options on the accuracy of dental implant-based single units and complete-arch frameworks. Int J Oral Maxillofac Implants 2014;29:1281-8.
39. Jiang X, Lin Y, Cui HY, Di P. Immediate loading of multiple splinted implants via complete digital workflow: A pilot clinical study with 1-year follow-up. Clin Implant Dent Relat Res 2019;21:446-53.
40. Gedrimiene A, Adaskevicius R, Rutkunas V. Accuracy of digital and conventional dental implant impressions for fixed partial dentures: A comparative clinical study. J Adv Prosthodont 2019;11:271-9.
41. Jemt T, Lie A. Accuracy of implant-supported prostheses in the edentulous jaw: analysis of precision of fit between cast gold-alloy frameworks and master casts by means of a three-dimensional photogrammetric technique. Clin Oral Implants Res 1995;6:172-80.
42. Katsoulis J, Takeichi T, Sol Gaviria A, Peter L, Katsoulis K. Misfit of implant prostheses and its impact on clinical outcomes. Definition, assessment and a systematic review of the literature. Eur J Oral Implantol 2017;(Suppl 1):121-38.
43. Kim KM, Lee JS, Kim KN, Shin SW. Dimensional changes of dental impression materials by thermal changes. J Biomed Mater Res 2001;58:217-20.

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