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RESEARCH AND EDUCATION

Accuracy of intraoral digital impressions using an artificial landmark

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ABSTRACT

Statement of problem. Intraoral scanners have been reported to have limited accuracy in edentulous areas. Large amounts of mobile tissue and the lack of obvious anatomic landmarks make it difficult to acquire a precise digital impression of an edentulous area with an intraoral scanner.

Purpose. The purpose of this in vitro study was to determine the effect of an artificial landmark on a long edentulous space on the accuracy outcomes of intraoral digital impressions.

Material and methods. A mandibular model containing 4 prepared teeth and an edentulous space of 26 mm in length was used. A blue-light light-emitting diode tabletop scanner was used as a control scanner, and 3 intraoral scanners were used as experimental groups. Five scans were made using each intraoral scanner without an artificial landmark, and another 5 scans were performed after application of an artificial landmark (a 4×3 mm alumina material) on the edentulous area. The obtained datasets were used to evaluate trueness and precision.

Results. Without an artificial landmark on the edentulous area, the mean trueness for the intraoral scanner ranged from 36.1 to 38.8 μm and the mean precision ranged from 13.0 to 43.6 μm. With an artificial landmark on the edentulous area, accuracy was improved significantly: the mean trueness was 26.7 to 31.8 μm, and the mean precision was 9.2 to 12.4 μm.

Conclusions. The use of an alumina artificial landmark in an edentulous space improved the trueness and precision of the intraoral scanners tested. (J Prosthet Dent 2017;117:755-761)

Since its introduction in the early 1980s, computer-aided design and computer-aided manufacturing (CAD-CAM) technology has improved accuracy and convenience.[1] The indications for CAD-CAM have been widely expanded, and the advancement of the system has transformed prosthodontic procedures.[1] For digital capture of the mouth, tabletop scanners, impression scanners, and intraoral scanners (IOS) have been used as part of the CAD-CAM system.[2] By using these scanners, dental prostheses can be fabricated by direct or indirect digitalization.[2]

An indirect digitalization system starts with a conventional impression poured in die stone[3] or by scanning the impression directly without cast fabrication in a dental laboratory.[4] The application of a tabletop scanner has changed many steps of the conventional process of restoration fabrication, and a dental restoration can be made simply by using CAD software and a milling system. In contrast, direct digitalization is done using an IOS. This technology eliminates the process of scanning conventional impressions or stone casts and has laid the groundwork for digitizing the entire prosthodontic process.

The data acquired from an IOS are sent to CAD software and used directly to design restorations, the data for which are then sent to a milling machine for fabrication. Unlike the conventional technique, impression materials and gypsum products are unnecessary, and problems such as distortion of impression materials, infection transmission from patient to technician,[5,6] gag reflex, and impression material allergies are eliminated or minimized.[7] Also, errors resulting from the dimensional change of the impression materials or gypsum casts are eliminated.[5]

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Clinical Implications

An artificial landmark can increase the precision of intraoral scanning in the fabrication of fixed partial dental prostheses with long edentulous spans.

Accuracy is defined as the combination of trueness and precision. Trueness is defined as the closeness between the actual reference object and the test object. Precision is defined as the closeness between the measurements of the test object as measured repeatedly.[8] The accuracy of the IOS has been demonstrated to be comparable with that of conventional technique for single crown and short-span partial fixed dental prostheses.[9-11] The evaluation of an entire arch with complete dentition demonstrated that digital impressions had similar accuracy to conventional impressions with polyether materials and greater accuracy than conventional impressions with alginate impression materials.[12]

However, the accuracy of IOSs for completely edentulous arches or implant overdenture frameworks is limited[13,14]; large amounts of mobile tissue make it difficult to acquire a precise digital impression of the edentulous space with an IOS. In addition, Flügge et al[15] reported that the accuracy of scanned data decreased with a long distance between dental implant scanbodies. Moreover, even when the attached gingiva or palate is stable, difficulties may arise with stitching the pictures acquired from an IOS because of the lack of clear anatomic landmarks.[13] Therefore, the use of IOSs for an edentulous space is limited.

To overcome these limitations, clinicians have described using artificial landmarks, although whether the artificial landmark technique increases the accuracy of an intraoral digital impression is unclear. To the best of the authors' knowledge, no in vitro study has estimated the accuracy of intraoral digital impressions using an artificial landmark.

The purpose of this study was to determine the effect of an artificial landmark on the accuracy of an intraoral digital impression by using a model of a mandibular dental arch with a long edentulous space and 4 prepared abutment teeth. The null hypothesis was that no difference would be found in the accuracy (trueness and precision) of intraoral impressions made with or without an artificial landmark.

MATERIAL AND METHODS

A mandibular Dentiform model with a partially edentulous area (KaVo study model; KaVo Dental GmbH) was used in this study. Among the artificial model teeth, the mandibular left third molar, mandibular left second molar, mandibular left canine, and mandibular left lateral incisor were prepared with a supragingival chamfer margin; half of the model contained the prepared teeth, while 26 mm in length of the edentulous space was used as a reference model (Fig. 1). A blue-light light-emitting diode tabletop scanner (Identica Hybrid; Medit Co) was used as a control scanner and results were compared with 3 IOSs (Table 1). All scans were made on the same day and under the same conditions by 1 examiner (A.A.), and all were performed in accordance with the manufacturers' instructions. Scans from the control scanner were compared with scans from the IOSs to measure trueness; the scan data from the same scanning conditions, such as the kinds of scanner or the presence or absence of artificial landmarks, were also compared to measure precision.

The Dentiform model was scanned using the control scanner (n=5), and 1 obtained data point (R1) of the 5 independent scans was compared with the intraoral scanning data to measure trueness. The Dentiform model was also digitized with 3 IOSs (CS3500; Carestream Dental, Cerec Omnicam; Dentsply Sirona, Trios; 3Shape A/S). Five scans (n=5) were made with each IOS without an artificial landmark, and another 5 scans (n=5) were made after an artificial landmark had been established on the edentulous space. The artificial landmark was a 4×3 mm alumina marker (Alumina marker; Dio implant Co). The intraoral scanning procedure maintained the alveolar ridge area (Fig. 2).

Additionally, as in the study by Patzelt et al,[5] after scanning with IOSs, a repeated reference scan (R2) was performed to compare with R1 in order to evaluate model deformation. Table 2 shows all the scanner systems used in this study and the number of scans performed by each scanner.

For standardization, datasets from each scan were converted to standard tessellation language (STL) file format. For the Cerec Omnicam scanner (OM) system, because of its closed system, the datasets were converted by using software (Cerec InLab v15; Dentsply Sirona). For the CS3500 (CS) scanner, the datasets were directly converted by the manufacturer's certified software. The files from the Trios (TR) scanner were saved in the Digital Imaging and Communications in Medicine (DCM) file format, and the datasets were converted to the STL file format by using CAD software (Exocad CAD software; Exocad GmbH). The datasets from the control scanner were saved directly in the STL file format.

The obtained datasets were used to evaluate trueness and precision. For the trueness measurements, selected reference scan R1 of 5 was compared with the IOS datasets. Before the datasets were superimposed, they were loaded into the Exocad dental CAD software, and 4 prepared abutments were separated from the surrounding structures. To compare the precision and trueness measurements, the obtained STL data were

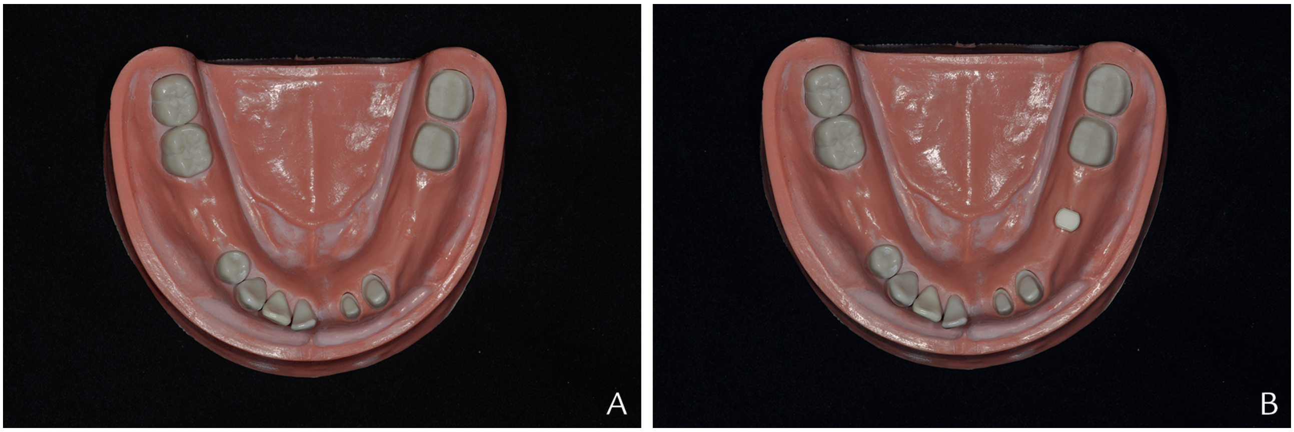

Figure 1. Mandibular Dentiform model containing 4 prepared teeth and 26-mm-long edentulous area. Mandibular left third molar, mandibular left second molar, mandibular left canine, and mandibular left lateral incisor of model teeth were prepared with a supragingival chamfer margin. A, Model without artificial landmark in edentulous area. B, Model with artificial landmark.

superimposed by using reverse engineering software (Rapidform 2006; INUS Technology Inc) (Fig. 3). The superimposition for comparison was performed by using 3-point registration and fine registration, and shell/shell deviation was carried out to evaluate absolute discrepancies of the datasets. The reference data (R1) were compared with the 5 datasets obtained from each different IOS (trueness), and each dataset from the same scanning condition was compared pairwise with the datasets obtained from the 5 scans (precision). In the precision analysis, as there was no reference to compare, scan data were compared pairwise within each dataset. Number of ways was calculated to select 2 of 5 scans by using combination formulas. There were 10 possible combinations (N=10). The absolute values were used to compare scan data in the Rapidform software.

All scan data were analyzed statistically to measure the trueness and precision of each group. Average discrepancy values acquired by comparing the 2 datasets were used for statistical analysis. Tests for the normality of each dataset were also performed. To analyze the difference of the trueness and precision between each group, the mean and standard deviation were calculated. All calculations were performed with statistical software (IBM SPSS Statistics v23.0; IBM Corp), and a 2-way ANOVA was used to assess the trueness and precision between IOSs and the effect of the artificial landmark (α=.05).

RESULTS

Table 3 shows the result of the mean precision and trueness measurements of the control scanner and IOSs. The reference scan data obtained from the control scanner, which were used to assess the trueness of the IOSs, was quite constant, and the mean deviation was 7.9 ±1.1 μm; therefore, standard deviations were low. Furthermore, the deviation was 6.2 μm when the reference dataset of the final reference scan, R2, was compared with the selected reference dataset R1. Thus, all scan processes were completed without significant model deformity.

Table 1. Scanners

Scanner	Manufacturer	Scanning Technology	Scanning Tip Size (mm)
CS3500	Carestream	Click and point	16×12
Cerec Omnicam	Dentsply Sirona	Continuous 3D color capture, active triangulation	16×16
Trios	3shape A/S	Confocal microscopy, continuous image	16×20

More time and images were needed for scanning with an IOS with an artificial landmark on the edentulous space. Although scanning procedures were successfully performed with the TR and CS, the OM had problems continuing to stitch; only the posterior area was scanned, with the exception of 2 anterior abutment teeth. With an artificial landmark on the edentulous space, less time was consumed, and all scanning procedures were performed successfully. As OM does not provide information to determine whether using a landmark is effective, it was not be considered in the analysis. Two-way ANOVA with a 2×2 design except for the OM group was performed to explore the effects of IOSs (TR, CS) and the alumina marker.

In the trueness analysis, the 2-way ANOVA indicated that the type of IOS (P=.893) and the use of the marker (P=.062) had no statistically significant effects. The interaction between the 2 factors (P=.461) also indicated no effect on trueness (Table 4). The mean trueness of IOSs is shown in Figure 4. Without an artificial landmark on the edentulous area, the mean trueness for the TR was 36.1 ±7.0 μm and 38.8 ±17.5 μm for the CS. The mean trueness for the OM could not be obtained because of scanning failure. With the presence of an artificial

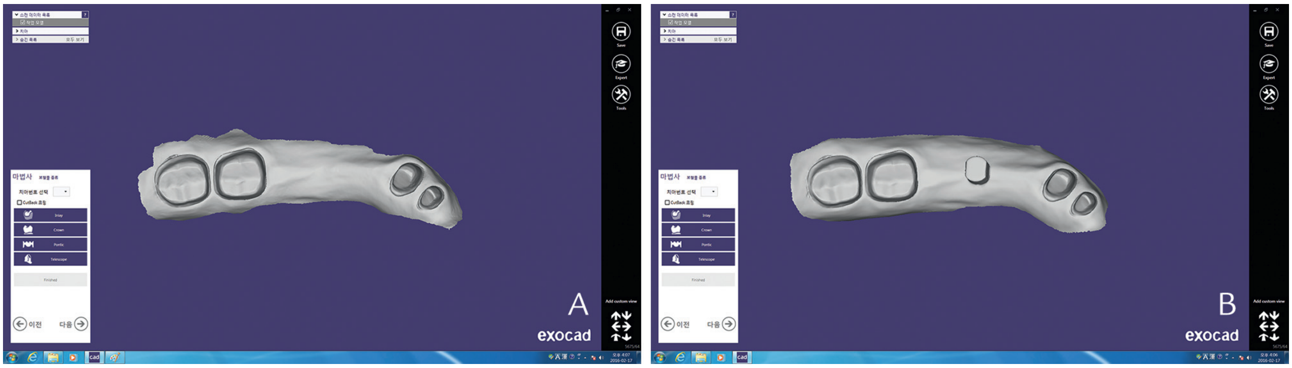

Figure 2. Scanned data of experimental model using intraoral scanner. A, Without artificial landmark. B, With artificial landmark.

landmark on the edentulous area, the mean trueness for the TR was 30.6 ±3.6 μm and 26.7 ±3.5 μm for the CS. The mean trueness was not significantly different. The mean trueness for the OM, meanwhile, was 31.8 ±5.4 μm; with an artificial landmark, the scan was completed without a problem.

In the precision analysis, the 2-way ANOVA showed that the type of IOS ($P<.001$) and the use of the marker ($P<.001$) had a significant effect. The interaction between the 2 factors ($P=.001$) also indicated a significant effect on precision (Table 5). The data demonstrated a quantitative interaction (Fig. 5). The mean precision of IOSs is shown in Figure 6. Without a marker on the edentulous space, the mean precision for the TR was 13.0 ±4.2 μm. However, the mean precision for the CS was 43.6 ±23.4 μm. In contrast, with an artificial landmark on the edentulous space, the mean precision improved significantly ($P<.001$). For the TR, it was 9.2 ±2.3 μm and 12.4 ±2.3 μm for the CS, whereas for the OM, the mean precision was 10.5 ±2.6 μm.

DISCUSSION

The results of this study showed no differences in mean trueness among the scanners tested, with or without the artificial landmark. However, because some differences in the precision analysis were found, the null hypothesis of the study was rejected for partially edentulous arch model scans with and without an artificial landmark ($P<.05$). With the use of a marker as an artificial landmark, all IOSs used in this study delivered significantly improved precision ($P<.05$).

After the application of an artificial landmark, the quality of the scan data from all IOSs used in this study was improved. It was also confirmed that the type of IOS could affect the quality of the scan data. In the case of the OM, scanning the model was impossible because of a failed stitching process without an artificial landmark, but after applying an artificial landmark, the scan was successful and showed low deviation. In contrast, the CS provided a complete scanning process even without the use of an artificial landmark. However, although the data obtained were very different from the reference data, showing a large deviation with every scan, a constant level of quality and relatively stable data was obtained after the application of an artificial landmark.

Table 2. Intraoral scans performed with and without marker

Scanner	No Marker	Marker
CS3500	5	5
Cerec Omnicam	5	5
Trios	5	5
Identica Hybrid	5	-
Identica Hybrid (R2)	1	-

This study showed an overall lower error value than that of existing research results by using a complete-arch scan model that evaluated the accuracy of the oral scanner. Patzelt et al[5] showed trueness of 38 to 332.9 μm depending on the type of IOS and a precision of 37.9 to 99.1 μm, whereas Ender et al[18] showed trueness of 29.4 to 44.9 μm and 19.5 to 63.0 μm of precision. However, this study showed 36.1 to 38.8 μm of trueness and 13.0 to 43.6 μm of precision without the application of an artificial landmark, and with the application of an artificial landmark, it showed 26.7 to 31.8 μm of trueness and 9.2 to 12.4 μm of precision. Trueness and precision data in this study showed a better overall accuracy than the existing complete-arch scan data, which seems to have occurred because of the design of the reference model. Unlike the study that used a complete-arch scan, this study created a model for the FPDP with a long edentulous span and scanned only the half-arch with prepared teeth. A large error was found in the opposite posterior teeth when the complete-arch with posterior teeth were scanned with an IOS.[5,17,18] Since 3-dimensional (3D) data are implemented using a stitching method from the starting point, the error is accumulated gradually. In clinical situations, intraoral scanning is performed only around the restoration produced; a complete-arch scan is not always performed. Therefore, the model design used in

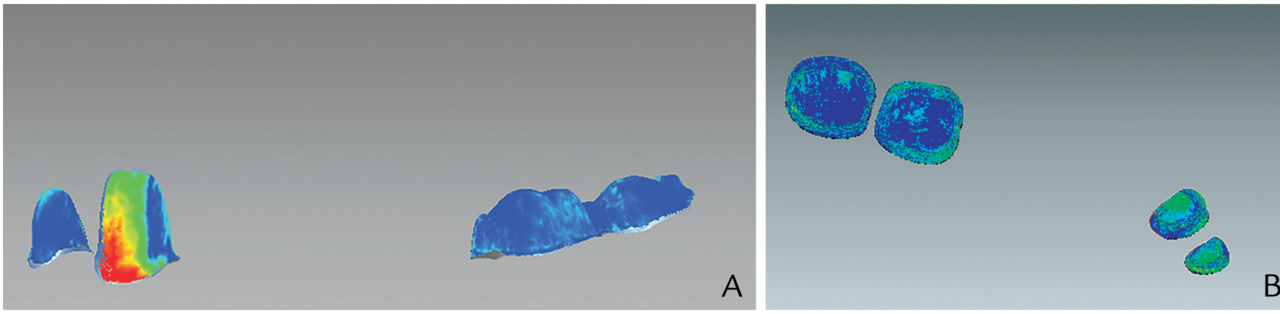

Figure 3. Superimposing and analyzing process using reverse engineering software. A, Data scanned by CS3500 scanner without applying artificial landmark showed large error (area represented by red color) at labial side of mandibular left canine. B, After using artificial landmark, almost no visible part of large error can be found.

this study is closer to an actual clinical situation. Recent improvements to the scanner and the software are another reason for better results. Therefore, compared with the data obtained in the previous studies, accuracy-improved data could be created.

The scanning areas of the tips in the scanners were another difference in the experiment. When the artificial landmark was not applied in the edentulous area in this experiment, the OM was the only scanner that failed to scan, related perhaps to the size of the scanning tip. A small tip compared with the length of the edentulous area is a limitation when it comes to overlapping scanned pictures. If the tip size is large, however, it can cause discomfort during the scan, particularly of the most distal molars.

The gingival area of the Dentiform model used in this study had a smooth surface not unlike natural gingival tissue. However, additional problems might be encountered in the actual clinical setting, such as surface reflections due to a saliva layer.[16] The model was not replicated in titanium or polyurethane as has been done in previous studies.[5,17]

In a clinical situation, for movable tissues like the frenum or tongue, an IOS does not provide accurate results because an afterimage could remain. Instead, a scan is performed of an area of soft tissue with less movement or no movement, such as the attached gingiva. This scanning method was used in this in vitro study. Because movable tissues such as the frenum cannot move in the experimental model, they can be used as a landmark for stitching that can lead to false positive bias in the accuracy assessment. Consequently, we were careful not to scan the area on the model that corresponded to the actual mobile tissue in the mouth but scanned only the part that corresponded to the attached gingiva.

The experimental model used in this study is not generally specified by the manufacturers of the IOSs. The starting point of this study was whether an FPDP with a long edentulous span could be fabricated in this

Table 3. Mean ±SD trueness and precision

	Trueness (N=5)*		Precision (N=10)*	
Scanner	No marker	Marker	No marker	Marker
Trios	36.1 ±7.0^{Aa}	30.6 ±3.6^{Aa}	13.0 ±4.2^{Aa}	9.2 ±2.3^{Ba}
CS3500	38.8 ±17.5^{Aa}	26.7 ±3.5^{Aa}	43.6 ±23.4^{Ab}	12.4 ±2.3^{Bb}
Cerec Omnicam**	Not obtained	31.8 ±5.4	Not obtained	10.5 ±2.6
Identica Hybrid	-	-	7.9 ±1.1	

*Different uppercase superscript letters significantly different within row for assessment of mean trueness and precision of effects of artificial landmark with same intraoral scanner. Different lowercase superscript letters significantly different within column for assessment of mean trueness and precision among scanners with same scanning condition.
**Because Cerec Omnicam scanner does not provide any information to determine whether using landmark is effective, it was not considered in analysis.

Table 4. Two-way ANOVA results for trueness analysis

Source of Variation	SS	*df*	MS	F	*P**
Marker	384.740	1	384.740	4.028	.062
Scanner	1.800	1	1.800	0.019	.893
Marker scanner	54.582	1	54.582	0.571	.461
Error	1528.191	16	95.512		
Total	23818.007	20			
Corrected total	1969.313	19			

ANOVA, analysis of variance; *df*, degree of freedom (n-1); MS, mean squares; SS, sum of squares. *Significant at $P<.05$.

model with a long edentulous area using IOSs and whether using an artificial landmark in the edentulous area could reduce error. Creating an FPDP with a long edentulous span using IOSs has several advantages. When clinicians use conventional impression techniques, they must remake the impression even if only 1 area is incorrect. However, with an IOS, pictures can be added if the scan is not performed correctly in certain areas. Patients with a gag reflex or allergic reaction to impression material or patients who do not like the taste or smell of impression materials can benefit from the production of prostheses using an IOS. Therefore, the intraoral scanning procedure would greatly help those patients who have difficulty with the conventional process of prosthetic fabrication.

Overall, this study confirmed that acquiring accurate and reliable data was possible when an artificial

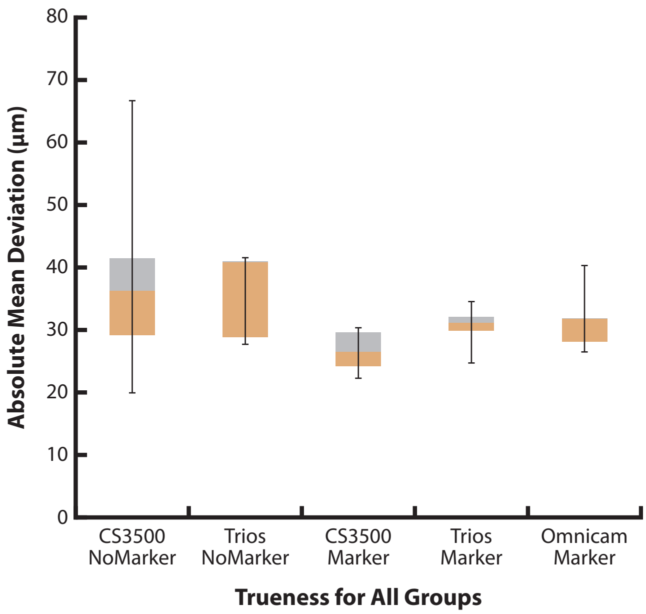

Figure 4. Trueness of intraoral scanners. Groups not applying artificial landmark showed large deviation.

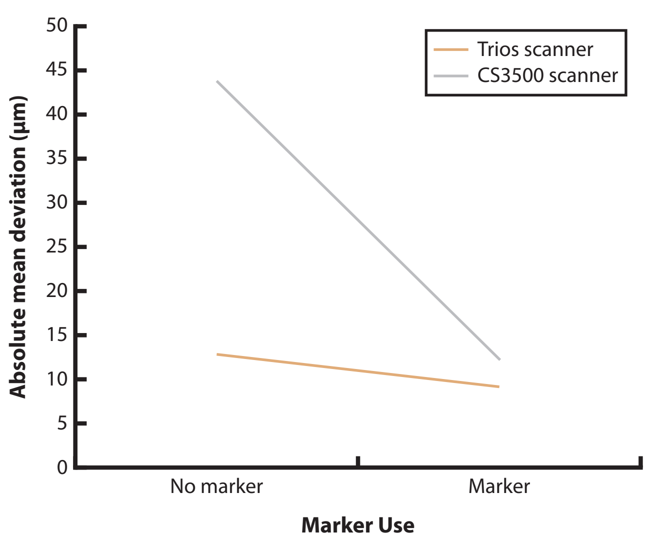

Figure 5. Mean precision data with or without artificial landmark.

landmark was used in the long edentulous area of the study model. However, this in vitro study has some limitations. In spite of the results of this study, the intraoral scan data in the actual oral cavity are likely to be different. This is because factors such as blood, saliva, shiny metal restorations, and tongue movement may interfere in the scanning process. In addition, since this study evaluated the accuracy of scan data using the best-fit algorithm for superimposition, the accuracy of inner surface and margin portion evaluated when the actual prosthesis is fabricated on the casts may vary. Further studies are required to evaluate the accuracy of using data recorded in the oral cavity or with an actual prosthesis.

Table 5. Two-way ANOVA results for precision analysis

Source of Variation	SS	*df*	MS	F	*P**
Marker	3075.639	1	3075.639	21.315	<.001
Scanner	2853.228	1	2853.228	19.774	<.001
Marker×scanner	1868.006	1	1868.006	12.946	.001
Error	5194.571	36	144.294		
Total	28251.014	40			
Corrected Total	12991.444	39			

ANOVA, analysis of variance; *df*, degree of freedom (n-1); MS, mean squares; SS, sum of squares. *Significant at $P<.05$.

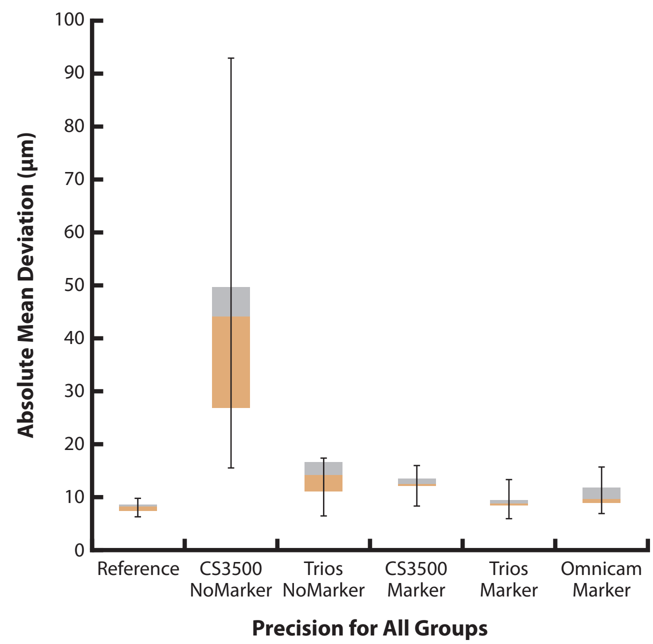

Figure 6. Precision of reference and all intraoral scanners. Large variations observed with CS3500 scanner without applying artificial landmark. After artificial landmark was applied, all groups had precision of 20 µm or lower.

CONCLUSIONS

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

1. Improved trueness and precision were obtained with an IOS if an artificial landmark in the long edentulous area was used.
2. Additional in vivo research will be needed to test this in clinical situations.

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Noteworthy Abstracts of the Current Literature

Flexural resistance of heat-pressed and CAD-CAM lithium disilicate with different translucencies

Fabian Fonzar R, Carrabba M, Sedda M, Ferrari M, Goracci C, Vichi A

Dent Mater 2017;33:63-70

Objective. To compare flexural strength of CAD-CAM and heat-pressed lithium disilicate.

Methods. Pressed specimens (Group A), acrylate polymer blocks were cut with a saw in bars shape. Sprueing, investing and preheating procedures were carried out following manufacturer's instructions. IPS e.max Press ingots (Ivoclar-Vivadent) were divided into subgroups (n=15) according to translucency: A.1=HT-A3; A.2=MT-A3; A.3=LT-A3; A.4=MO2. Ingots were then pressed following manufacturer's instructions. For CAD-CAM specimens (Group B) blocks of IPS e.max CAD (Ivoclar-Vivadent) were divided into subgroups: B.1=HT-A3; B.2=MT-A3; B.3=LT-A3; B.4=MO2. Specimens (n=15) were obtained by cutting the blocks with a saw. Final crystallization was performed following manufacturer's instructions. Both Press and CAD specimens were polished and finished with silica carbide papers of increasing grit. Final dimensions of the specimens were 4.0±0.2mm, 1.2±0.2mm, and 16.0±0.2mm. Specimens were tested using a three-point bending test. Flexural strength, Weibull modulus, and Weibull characteristic strength were calculated. Flexural strength data were statistically analyzed.

Results. The overall means of Press and CAD specimens did not differ significantly. Within the Press group different translucencies were found to have similar flexural strength. Within the CAD group, statistically significant differences emerged among the tested translucencies ($p<0.001$). Specifically, MT had significantly higher flexural strength than HT and MO. Also, LT exhibited significantly higher flexural strength than MO.

Significance. The choice between IPS e.max Press and IPS e.max CAD formulations can be based on different criteria than flexural resistance. Within each formulation, for IPS e.max Press translucency does not affect the flexural strength while for IPS e.max CAD it is an influential factor.

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