Accuracy of Intraoral Scanners in Definitive Implant Prosthesis Workflow: A Comparative Analysis of the Cut-out Rescan and Direct Scan Methods

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이찬규 올림

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ABSTRACT

Accuracy of Intraoral Scanners in Definitive Implant Prosthesis Workflow: A Comparative Analysis of the Cut-out Rescan and Direct Scan Methods

One option for capturing the soft tissue profile of a dental implant or the shape of temporary restorations used by the patient is to employ a cut-out technique and rescan the region surrounding the implant using an intraoral digital impression. Nevertheless, the level of precision of the digital implant created with this technique remains uncertain in terms of accurately capturing the patient's intraoral anatomy. Therefore, the purpose of this study was to determine the accuracy and linear displacement of digital implant impressions when using the cut-out rescan method in comparison with the direct scan method, specifically in terms of the reproducibility of the implant position.

The implant model was scanned ten times using one laboratory scanner and five intraoral scanners (IOSs). The IOSs utilized two scanning methods (direct scanning and cut-out rescanning). The trueness and precision of each IOS and the reproducibility of the implant position were evaluated. Statistical analyses were performed using one-way ANOVA with a significance level of a $\alpha = 0.05$.

The trueness of each IOS while using the cut-out rescan method was comparable to that when using direct scanning methods. However, the precision was significantly worse for the cut-out rescan method when using the CEREC Primescan (direct scan: 18.92 ± 6.66 µm [mean ± standard deviation], cut-out rescan: and 34.40 ± 19.89 µm for direct scanning and cut-out rescanning, respectively) and the IS 3800W (direct scan: 19.38 ± 9.10 µm and, cut-out rescan: 39.05 ± 19.93 μm, respectively). The implant position displacements were generally small minor, except for the TRIOS 3 (F = 183.852, p < 0.001) and the RAYiOS (F = 4.390, p < 0.001), for which there were exhibited significant vertical displacements when using the cut-out rescan method.

While the differences in implant positioning in horizontal dimensions were generally small, substantial vertical displacements were observed when using the TRIOS 3 and RAYiOS with the cut-out rescan method. Careful evaluations of scanning techniques are necessary for the developing appropriate prosthetic strategies for specific clinical cases.

Key words : intraoral scanner, implant scan body, trueness, precision, implant displacement

1. INTRODUCTION

One of the important initial steps in dental prosthodontics is obtaining an impression of a patient's oral cavity to accurately replicate the teeth, the adjacent soft tissue structures, and the occlusal relationships (Saeed et al., 2020). Conventional impression methods utilized custom or stock trays made of resin, polycarbonate, or metal and alginate, agar, polyether, and polyvinyl siloxane impression materials (Gupta et al., 2017; Saeed et al., 2020). Traditional impression methods have been extensively used and demonstrated clinically acceptable results (Cao et al., 2023; Yun et al., 2017). Furthermore, these methods are relatively accessible as they are inexpensive to do and require only simple tools, and the technique is not difficult (Christensen, 2008). However, potential distortion of the impressions may occur during the dental model fabrication process, e.g., bubbles, foreign materials, operator errors stemming from clinical inexperience and varying skills, and environmental conditions including temperature and humidity (Christensen, 2008; Murugesan and Sivakumar, 2020). Moreover, traditional impression methods may leave markings on the patient's skin, mucosa, or the areas with tooth undercuts. Furthermore, patient discomfort including nausea, gag reflex, and tastes issues are common disadvantages (An et al., 2014; Punj et al., 2017).

Recent technological advances in the field of implant prosthodontics such as intraoral scanners (IOSs) have mitigated some of the drawbacks of traditional impression techniques (Schott et al., 2019). Digital impressions taken using an IOS eliminate the need for physical-impression trays or materials, reducing the probability of deformation due to the inherent properties of traditional impression materials as well as during shipping or storage

(Kihara et al., 2020). In addition to these logistics advantages, using an IOS speed up the transfer of scan data to the dental laboratory, streamlines the impression-taking process, reduces the risk of infection, and means that the data are stored as a digital file for easy retrieval when used in future replication or repair procedures (Ahmed et al., 2021; Kihara et al., 2020).

However, several problems associated with IOSs have been reported. Although these devices represent a significant technological leap forward, their novelty makes them expensive to purchase and maintain, and results in the proficiency of dental clinicians and allied oral-health professionals in using IOSs being a critical factor in determining outcomes (Mangano et al., 2017). In addition, various factors such as the presence and extent of soft tissue, saliva, and/or blood in the patient, anatomical landmarks in the scanning area, and the scanning range also affect the accuracy when using IOSs (Braian and Wennerberg, 2019; Schmidt et al., 2020).

The IOS enables the creation of definitive implant prosthetics via a digital workflow. The accuracy of the IOS can significantly influence the quality of the implants or prostheses fabricated (Mangano et al., 2017). Accuracy is evaluated using trueness and precision, as defined by ISO 5725-1. Trueness assesses the degree to which the data obtained from intraoral scanning corresponds to the reference scan data, thus providing a measure of how accurately the scanner captures the true form. Conversely, precision involves comparing data obtained during the intraoral scanning process under identical conditions, which determines the level of agreement and accuracy between the scans (Oh et al., 2020). These metrics are critical for ensuring the reliability and quality of digital impressions, ultimately impacting the successful production of implants and other prosthetics for patients (Marques et al., 2021).

When fabricating implant restorations for patients using an IOS, it is often necessary to obtain multiple data sets to ensure that the recorded data are consistent. This can be achieved by removing the peri-implant area using the cut-out function after the initial scan, connecting the scan body, and then rescanning the area (Revilla-León et al., 2023b). This is important in the context of implant restoration design because it helps to accurately capture the shape of the tissue-molded gingival profile or the shape of the patient's existing provisional restoration, thus contributing to the design of an optimal prosthesis (Gómez-Polo et al., 2023). In addition, during the process of designing implant prostheses, it is essential to match library data at the level of the abutment or implant fixture to the scan body regions.

The accuracy of IOSs was evaluated by analyzing the effects of using from zero to three rescanned mesh holes in an implant model (Gómez-Polo et al., 2023). Their results demonstrate that the trueness was significantly better when there was either no or only one mesh hole, and that the precision was best when no mesh holes were present, although the differences among the groups were not statistically significant. Those authors concluded that the rescanning process could negatively impact the scanning accuracy and so they recommended minimizing such procedures in order to improve outcomes. However, no studies have investigated the accuracy of the cut-out rescan method by matching the library data to the actual digital design process. Since the application of the library data has the potential to address scanning errors in the scan body, evaluation studies following the same process as in the real world are needed (Kim et al., 2019). Furthermore, studies are needed to measure the errors in the horizontal and vertical directions in order to properly quantify the errors that occur during the fabrication of a prosthesis.

Therefore, this study performed an in vitro comparative analysis of the accuracy and linear displacement between data that had undergone a cut-out rescan process and data captured by direct scanning after aligning a cylinder abutment library to scan data. The following hypotheses were investigated: (1) using the cut-out rescan method does not significantly affect the accuracy (trueness and precision) and (2) using the cut-out rescan method does not significantly affect the linear displacement.

2. MATERIALS AND METHODS

2.1. Model fabrication

2.1.1. Model design

The experimental workflow commenced with the design and three-dimensional (3D) printing of a full-arch dental model (**Figure 1**). A maxillomandibular tooth dentiform model (D85DP-500B.1, Nissin, Kyoto, Japan) was scanned using a tabletop scanner (Identica T500, Medit, Seoul, Republic of Korea) with an accuracy <7 µm according to ISO 12836 and used as the study model (Shin et al., 2021). The maxillary first molar was virtually extracted, and the adjacent distal third of the second premolar and mesial third of the second molar were removed using computer-aided design (CAD) software (Dental CAD, Exocad, Darmstadt, Germany). The antagonist to the extracted maxillary tooth was digitally prepared by removing approximately half of the occlusal surface, and the model was saved as a standard tessellation language (STL) file.

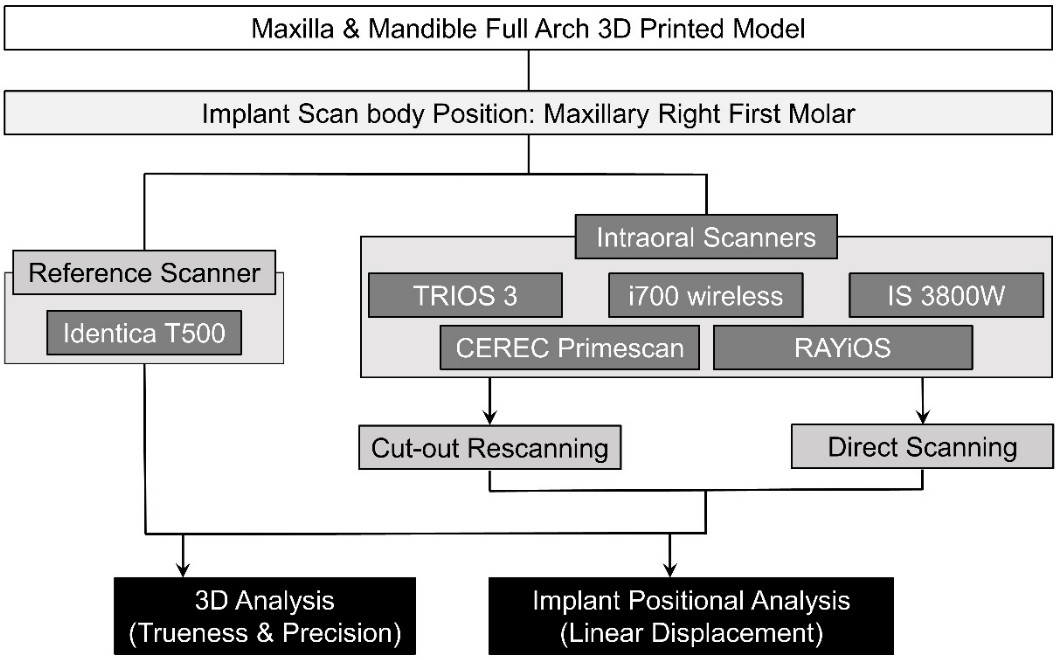

Figure 1. Overall study workflow for different IOSs and scanning methods.

The maxillary dental-arch STL file was printed in three dimensions by a digital light processing 3D printer (NextDent 5100, NextDent, Soesterberg, the Netherlands) using a model resin (NextDent Model 2.0, NextDent). An internal bone-level implant fixture with (4.0 mm × 10 mm; TS System Regular**,** Osstem Implant, Seoul, Republic of Korea) was inserted into the printed model at the site of the extracted tooth to simulate implant placement.

A titanium implant scan body (TS Scan Body Regular, Osstem Implant) was hand-tightened and scanned using a laboratory scanner (Identica T500, Medit). CAD software (Design Studio, 3shape, Copenhagen, Denmark) was used to import the digital library for the digital laboratory analog (Digital Lab Analog TS Regular, Osstem Implant) to make room for the laboratory analog component. Additional modifications were made to the model using CAD software (Meshmixer, Autodesk, San Rafael, CA, USA), including attaching 3-mm-diameter spheres to the contact areas between the adjacent teeth and the occlusal surface of the mandibular right first molar, which represented the antagonist tooth. The internal structure was hollowed, and the modified model was exported as an STL file.

2.1.2. 3D printing

The virtual model was imported to a slicing software (Preform, Formlabs, Somerville, MA, USA) and prepared for 3D printing using standard grey resin (Grey Resin V4, Formlabs). The model was printed with a stereolithography 3D printer (Form 3, Formlabs) with a layer thickness of 0.1 mm and an orientation of 0˚. Moreover, support structures were added to the base of the model. Fabrication of the study model was completed after postprocessing, which involved washing the model in a rotary machine (TwinTornado, Medifive, Seoul, Republic of Korea) for 10 min using 95% ethylene alcohol, postcuring at 60°C for 40 min using a postcuring device (Form Cure, Formlabs), and securely attaching the digital lab analog to the model.

2.2. Digitalization of study model

2.2.1. Model scan

The fabricated study model was scanned using the following five IOSs (**Table 1**): CEREC Primescan (group PR; Dentsply Sirona, North Carolina, Charlotte, NC, USA), TRIOS 3 (group TR; 3shape), i700 wireless (group i700; Medit), IS 3800W (group IS; DEXIS™, Quakertown, PA, USA), and RAYiOS (group RAY; Raydent, Seoul, Republic of Korea). The model was also scanned with a laboratory scanner as a reference: Identica T500 (group REF; Medit). Scan bodies (TS Scan Body Regular, Osstem Implant) were hand-tightened onto the digital laboratory analogs in accordance with the manufacturer's recommendation. The configuration of the bevel feature of the implant scan body was oriented toward the buccal surface during the scanning process.

Table 1. Dental scanners used in this study.

Type	Name	Group	Scan Technology
Reference scanner	Identica T500	REF	Phase-shifting optical triangulation
Intraoral scanner	CEREC Primescan	PR	Confocal microscopy with Smart Pixel Sensor
	TRIOS 3	TR	Confocal microscopy technology / Ultrafast optical sectioning
	i700 wireless	i700	3D-in-motion video technology / 3D full color streaming capture
	IS 3800W	IS	1/2.9-inch CMOS
	RAYiOS	RAY	Digital structured light projection / Realtime video process scanning

All of the IOSs were calibrated prior to performing scanning. Each arch was scanned from the right central second molar while focusing on the right region. The scanning sequence started from the right second molar to the occlusal, lingual, and buccal (labial) surfaces, and ended at the right central incisor (**Figure 2**; Oh et al., 2020). The two scanning methods (direct scanning and cut-out rescanning) were used with each IOS. The direct scan method involved attaching the scan body to the digital laboratory analogs. In the cut-out rescan method, this was followed by the implant scan workflow of each scanner. The scanning workflow began with scanning the model without a scan body, followed by the removal of the emergence profile area. The scan body was then attached, and the corresponding area was rescanned. For devices without a recommended cut-out rescan workflow (group PR), the "edit" tool was used to delete the emergence profile area before performing the rescanning process.

Each scanner was used to perform 10 scans for each scanning method. High-resolution and bite-adjustment functions were not utilized to control the scanning conditions of the IOS when scanning the model. The reference scanner used a direct scan method to scan the entire arch. All files were saved in the STL format after scanning.

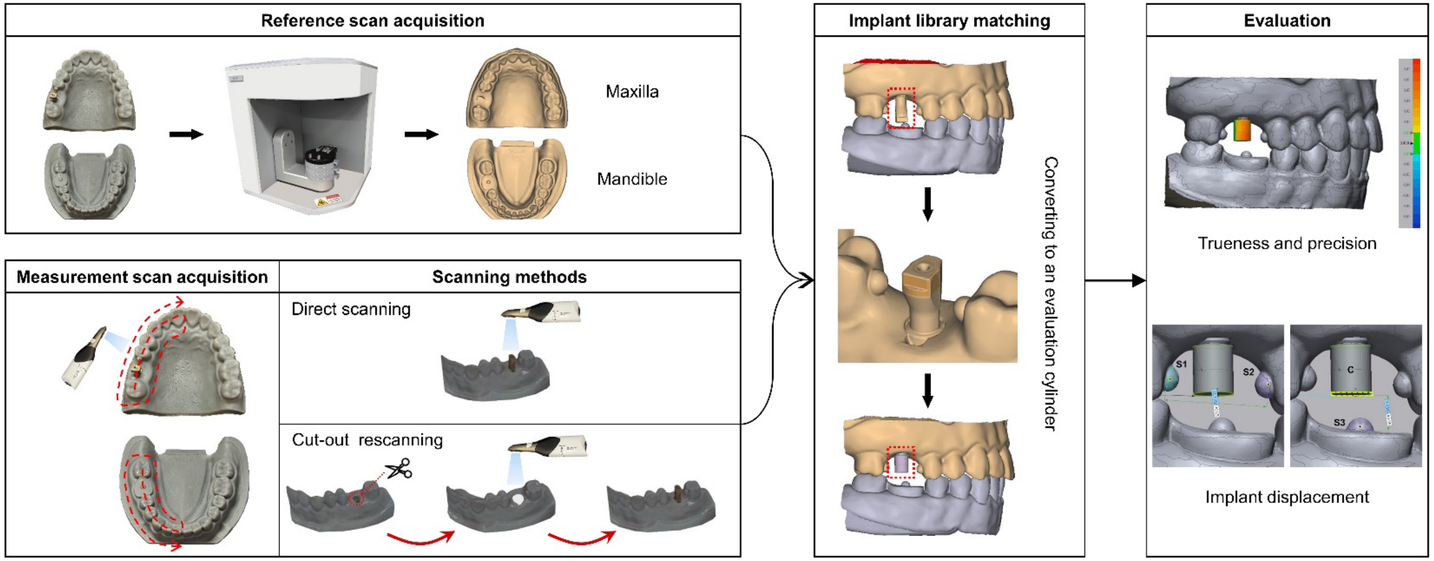

Figure 2. Illustration of the scan acquisition process, including direct scan and cut-out rescan methods, conversion of the scan body to an evaluation cylinder, and subsequent evaluations.

2.2.2. Converting to an evaluation cylinder

The scanned STL files were processed in CAD software (Dental CAD, Exocad), where the scan bodies were matched to the library using a best-fit matching method. Subsequently, a virtual cylinder with a diameter of 4.5 mm and a height of 5.5 mm was used to incorporate the implant position. Ultimately, the virtual model representing the occlusion between the maxilla and the mandible, including the cylinder, was saved as an STL file for subsequent analyses. (**Figure 2**).

2.3. 3D evaluations

2.3.1. Evaluation of cylinder accuracy

Prior to analyzing the trueness, the files acquired using each IOS were labeled as measurement scans (MS), while those from group REF were categorized as reference scans (RS). One file was then randomly selected from the 10 scans in group RS and loaded into the evaluation software (Geomagic Control X, 3D Systems, Rock Hill, SC, USA) along with an MS file. The RS file was divided into multiple segments using the “auto segment” function, designating the virtual cylinder (labeled “C” in **Figure 3**) using the “cylinder” tool. The MS and RS were aligned first using the “initial alignment” function followed by the “best-fit alignment” function. The “3D compare” option was then used to calculate the trueness of the cylinder abutment, quantifying the size difference between RS and MS as the root mean square (RMS) error:

$$RMS = \frac{1}{\sqrt{n}} \cdot \sqrt{\sum_{i=1}^{n} (x_{ref} - x_i)^2}$$

where x_{ref} represents the data generated from the RS, x_i represents the data from each MS relative to the RS, and n denotes the total number of measurements. All measurements were recorded in micrometers. Precision was assessed within each RS and MS group by superimposing and measuring the RS and MS pairs, respectively.

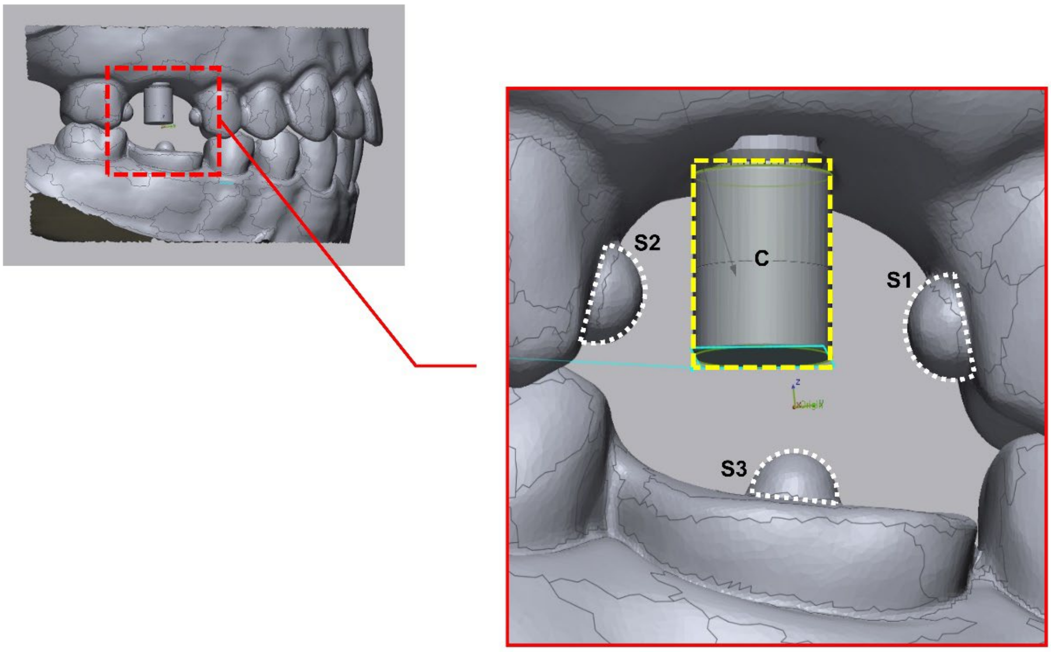

Figure 3. Definitions of measurement points and areas: S1, sphere 1; S2, sphere 2; S3, sphere 3; and C, cylinder.

2.3.2. Evaluations of linear distances and implant displacements

The "auto segment" function was applied to each MS file, for which the software automatically recognized spheres on both contact areas and applied the "cylinder" tool in Geomagic Control X. The bottom surface of the cylinder abutment was further divided by using the "split" and "plane" features. The following specific coordinate points were assigned for the analyses: the distal aspect of the right maxillary second premolar as sphere 1 (S1), the mesial aspect of the right maxillary second molar as sphere 2 (S2), and the right mandibular first molar as sphere 3 (S3) (**Figure 3**). The lengths of line segments S1S2, S2S3, S1S3, CS1, CS2, and CS3 were calculated using the "linear dimension" function. In particular, CS1 and CS2 measured the distances to the center coordinates of the cylinder, while CS3 measured the length from S3 to the bottom surface of the cylinder (**Figure 4**). The distances measured from RS and MS were designated as the reference scan distance (RSD) and the measurement scan distance (MSD), respectively. The implant linear displacement (ΔD) was calculated using RSD and MSD:

$$\Delta D = x_{ref} - x_i$$

where x_{ref} represents the RSD and x_i represents the MSD.

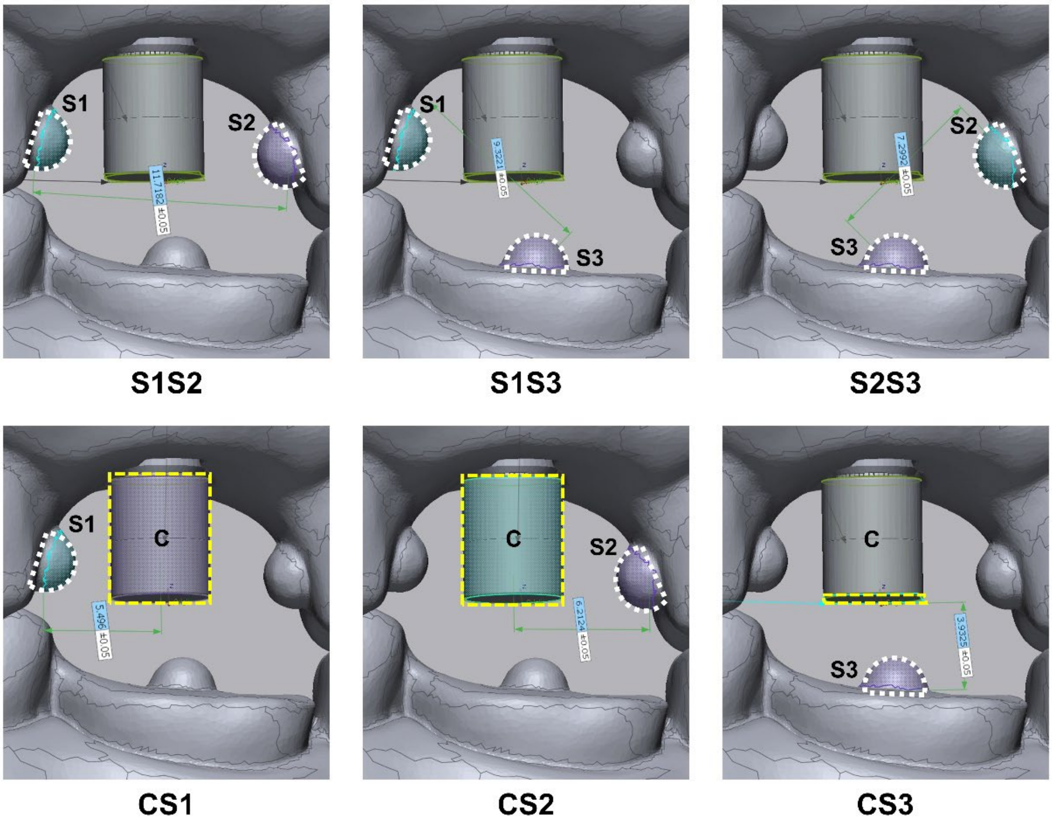

Figure 4. Definitions of linear measurements: S1S2, sphere 1 to sphere 2; S1S3, sphere 1 to sphere 3; S2S3, sphere 2 to sphere 3; CS1, cylinder to sphere 1; CS2, cylinder to sphere 2; and CS3, cylinder to sphere 3.

2.4. Statistical analyses

Statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS version 26, IBM, Armonk, NY, USA). Normality tests including the Shapiro-Wilk test and Levene's test were used to assess the homogeneity of variances for all experimental groups. One-way analyses of variance followed by pairwise comparisons using Bonferroni adjustments were used to detect significant differences in trueness, precision, and ΔD according to the scanning method. A significance cutoff of $\alpha = 0.05$ was applied in all tests.

3. RESULTS

3.1. RMS analyses

The findings of the trueness and precision evaluations are presented in Figure 5 and 6, where a lower RMS error indicates better trueness and precision. The RMS errors measured for each IOS were similar when using the direct scan and cut-out rescan methods, with no significant differences in the trueness (**Figure 5**).

When using the cut-out rescan method, the RMS error was lowest in group i700, at 51.90 ± 22.12 μm (mean ± standard deviation), showing the highest similarity to group REF. In contrast, the RMS error was highest in group RAY (69.79 ± 39.28 μm), indicating the lowest similarity. When using the direct scan method, the RMS error was lowest in group IS (50.61 ± 10.58 μm) and highest in group RAY (69.02 ± 30.39 μm). The RMS error was lower for direct scanning than for cut-out rescanning method (implying higher accuracy) in all groups other than group i700 (**Figure 5**).

Repeatability was better when using scanners with the direct scan method, with lower RMS errors than when using the cut-out rescan method. The RMS error was significantly lower for direct scanning than for cut-out rescanning in group PR ($p = 0.014$) and group IS ($p < 0.001$). The RMS error was lowest in group IS (19.38 ± 9.10 μm) when using the direct scan method, and highest in group RAY (55.59 ± 31.16 μm) when using the cut-out rescan method (**Figure 6**).

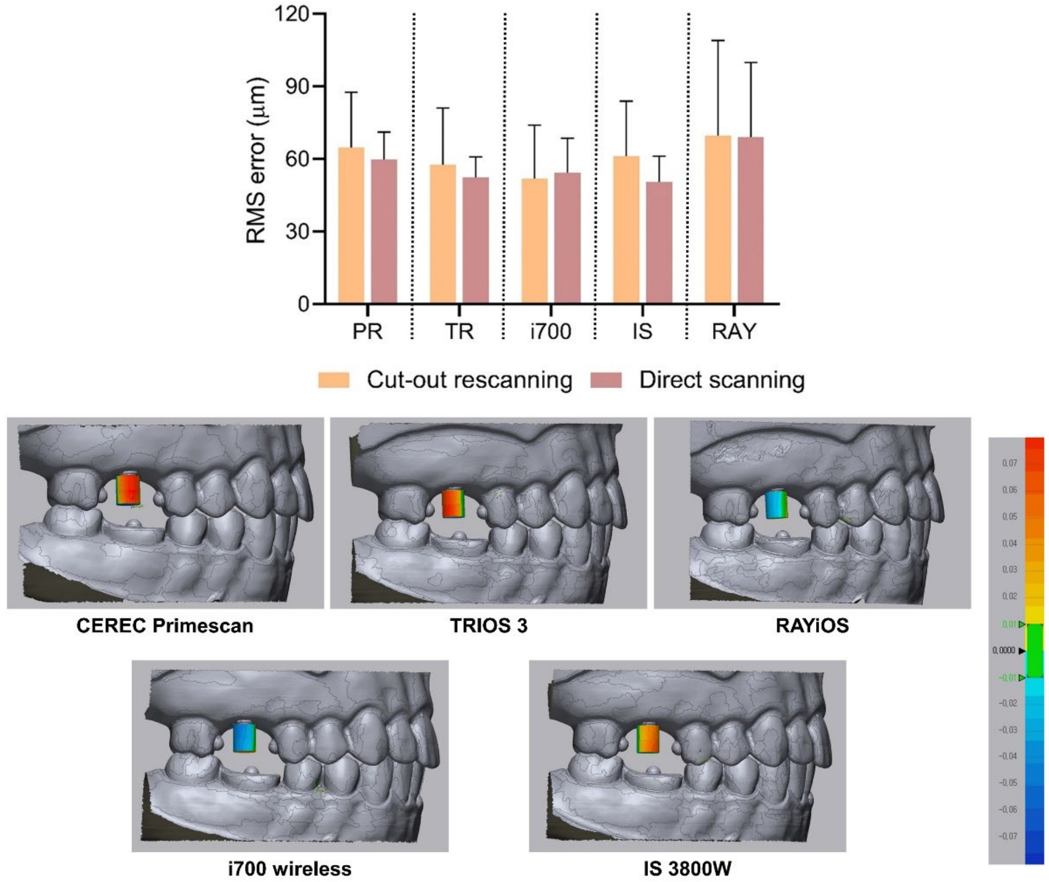

Figure 5. RMS errors and representative color maps of trueness for the different IOSs. Data are mean and standard deviation values.

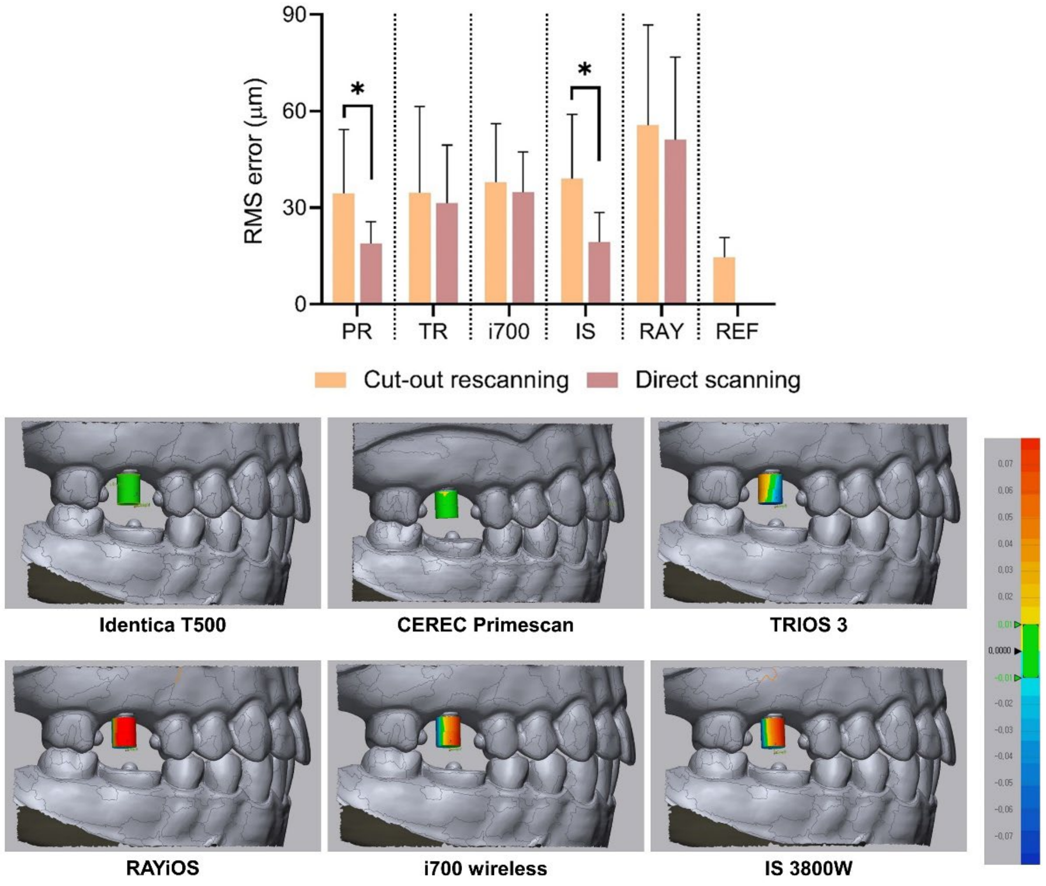

Figure 6. RMS errors and representative color maps of precision for the different IOSs. Data are mean and standard deviation values. Asterisks indicate statistically significant differences ($p < 0.05$).

3.2. Implant linear displacement

The relationships between the linear distance and implant displacement for the various IOSs are shown in Figure 7. A positive Δ*D* indicates that the length in group REF was larger than that of the particular IOS, while a negative Δ*D* indicates that the length was smaller in group REF. In group PR, no significant displacement was observed between the direct scan and cut-out rescan methods across all positions. The largest displacement recorded was –147.4 ± 25.0 µm for CS3 using the direct scan method (**Figure 7A**).

Significant differences were noted in group TR between the two scanning methods for S2S3 (–36.7 ± 18.1 µm and –77.6 ± 31.7 µm for direct scanning and cut-out rescanning, respectively; $p = 0.001$), CS2 (28.1 ± 16.4 µm and –4.7 ± 18.8 µm, respectively; $p = 0.037$), and CS3 (–152.9 ± 25.2 µm and –191.6 ± 29.3 µm, respectively; $p = 0.004$) (**Figure 7B**). In group RAY, the direct scan method resulted in larger displacements for S2S3, CS2, and CS3 than the cut-out rescan method. Significant displacement was noted in CS3 between the methods (83.3 ± 50.3 µm and –0.8 ± 40.7 µm, respectively; $p = 0.022$) (**Figure 7C**).

No significant displacement differences were observed in group IS between the methods for the various distances ($p > 0.05$). Displacements were primarily found to occur in S1S2, S2S3, and CS3, reflecting the inherent inaccuracies of the scanner and postacquisition expansion between the upper and lower arches. The displacement was largest for CS3 with direct scanning (–169.6 ± 30.5 µm) (**Figure 7D**). In group i700 there were no significant displacements between direct scanning and cut-out rescanning for all linear distances. The i700 showed better overall performance than the other IOSs, with the smallest displacement in S1S3 (0.09 ± 62.4 µm) and the largest displacement in CS3 (–54.2 ± 63.5 µm) when using the direct scan method (**Figure 7E**).

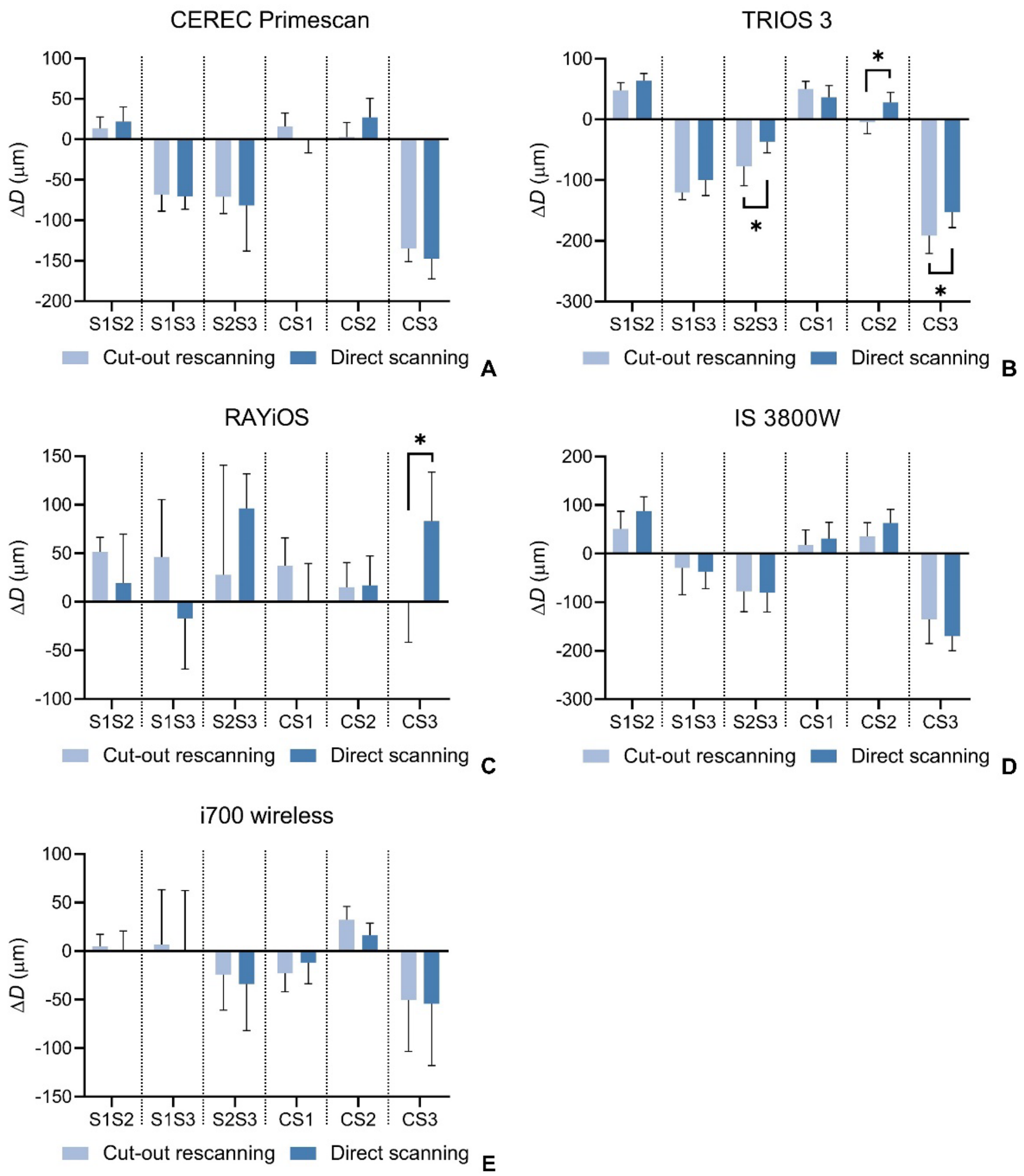

Figure 7. Implant displacements for the five IOS: (A) CEREC Primescan, (B) TRIOS 3, (C) RAYiOS, (D) IS 3800W, and (E) i700 wireless. Asterisks indicate statistically significant differences ($p < 0.05$).

4. DISCUSSION

This study compared the accuracies of the cut-out rescan and direct scan methods in terms of implant areas and displacements. The RMS error for trueness was higher for all IOSs other than the i700 when using the cut-out rescan method. In addition, using that method resulted in statistically significant lower precision in both groups PR and IS. For linear displacement, no statistically significant differences were observed between the direct scan and cut-out rescan methods in groups i700, IS, and PR. However, significant differences were noted for CS3 in group RAY and for S2S3, CS2, and CS3 in group TR. Thus, the null hypothesis was partially rejected.

Trueness and precision are key parameters in digital implant prosthodontics for evaluating the accuracy of an IOS (Afrashtehfar et al., 2022; Demirel et al., 2023; Sanda et al., 2021). Previous studies have found high accuracies when using various IOSs to take implant impressions (Demirel et al., 2023; Mangano et al., 2019; Sultanoğlu and Eroğlu, 2023). However, few studies have evaluated how using a cut-out rescan method to obtain implant impressions affects the trueness and precision. Reich et al. recently assessed using the cut-out rescan method with three IOSs (TR, PR, and Cerec Omnicam) in complete arch scans (Reich et al., 2021). The trueness values for direct scanning and cut-out rescanning using the TR device were reported as 42 ± 5 μm and 38 ± 5 μm, respectively; the corresponding precision values were 18 ± 3 μm and 17 ± 4 μm, respectively. For the PR device, the trueness was 29 ± 3 μm for direct scanning and 31 ± 5 μm for cut-out rescanning, while the precision values were 15 ± 5 μm and 16 ± 5 μm, respectively. Those authors found no significant differences in trueness or precision between the two scanning methods for each scanning system. In contrast, the present study found that the precision differed significantly between the two scanning methods in groups PR and IS but not in the other groups, and also no significant differences in trueness among all of the scanners.

In groups PR, TR, and IS, the ΔD values for S1S3, S2S3, and CS3 were found to be negative and significantly different from the values at other sites. This suggests that when using these three IOSs, specific displacements could occur when measuring distances that contain S3, and especially CS3, which corresponds to displacement toward the vertical dimension. These displacements might be related to the bite registration process that was applied during scan acquisition (Kakali and Halazonetis, 2023). The process of retracing the scanning method involves three steps: (1) scanning the maxillary arch, (2) scanning the mandibular arch, and (3) aligning these two arches using bite registration (Jin et al., 2020). The bite-registration acquisition process in group REF involved placing the cast model on the plate and applying several rotations to obtain sufficient scan data for generating the bite registration. In contrast, the utilization of an IOS involves placing the model cast in a stable position on a table for scanning the maxillary and mandibular arches and performing bite registration. The fundamental difference between these two approaches is the stability of the model cast and the algorithm employed for the required calculations. Aligning the arches in group REF resulted in compression relative to groups TR, IS, and PR. Additionally, exerting forces on the cast material can interfere with bite registration (Okamoto et al., 2023). A similar issue may occur when registering a bite for a patient using an IOS, since variations between applying small and large bite forces can cause errors. These errors can propagate through the manufacturing process, leading to the production of inferior prostheses. Therefore, clinicians should be cautious when instructing patients to bite down, ensuring they do not bite too forcefully or loosely, as either can lead to discrepancies in the distance between the upper and lower antagonist teeth. Such variations in biting force can result in inaccurate occlusal records, affecting the accuracy of subsequent fabrications.

Significant differences in displacements between the direct scan and cut-out rescan methods were noted in groups TR and RAY. The cut-out rescan feature built into the IOS used in group TR reduced the linear displacement for CS2 but increased it for S2S3 and CS3. In group RAY this method significantly reduced the displacement for CS3, improving the reproduction of the implant height, but it resulted in no significant improvements for the other distances. These results suggest that the cut-out rescan feature is inadequate for correcting acquisition errors relative to using the direct scan approach.

The impact of the cut-out rescan function on a maxillary arch was investigated by Passos et al. using the PR, focusing on a central incisor and two first molars (Passos et al., 2022). They found that the overall trueness and precision surpassed those obtained when using direct model scanning. Although the present study did not observe significant improvements for most of the investigated IOSs, this technique may be beneficial when designing complex implants or prostheses, since the accuracy can decrease when scanning multiple implants or metal prostheses (Carneiro Pereira et al., 2023; Kernen et al., 2023; Revilla-León et al., 2023a). For example, scanning multiple implants often involves making repeated passes over reflective metal surfaces, which can lead to cumulative scanning errors due to light reflections. The cut-out rescan method allows the surrounding tissues around the implant to first be accurately captured, followed by precise scanning of the implant itself. It has also been found previously that the accuracy of the IOS decreased as the arch span increased (Abduo and Elseyoufi, 2018; Diker and Tak, 2022). Thus, the cut-out rescan method might improve the accuracy for multiple-implant models, especially in clinical applications involving complete or partial edentulism. However, the present study only used a single-implant model to simulate situations where a single implant is placed next to two teeth. Further evaluations of the cut-out rescan method are therefore needed for models involving partial or complete edentulism.

When discrepancies exceed 100 µm, adjusting prostheses using shimstock or occlusal papers becomes problematic in clinical settings. Therefore, the clinically acceptable tolerance should be set below 100 µm (Jin et al., 2022; Rungrojwittayakul et al., 2020; Yatmaz et al., 2023). In the present study, the trueness and precision of the RMS error for the two scanning methods of each scanner, after converting the implant library into evaluation cylinders, were all measured to be below 100 µm. These findings suggest that the accuracy remains consistent even after using the library conversion process following intraoral scanning in the implant workflow, indicating high applicability in clinical practice.

This study had some limitations. It was conducted in vitro, and so the conditions might not have fully encompassed the complexities of the real oral environment. This might have compromised the applicability of the accuracy and reproducibility findings to clinical practice. Also, while five different IOSs were investigated, other commercially available scanners may exhibit different performance characteristics. Further evaluations of other IOSs are therefore needed to further validate the findings of this study.

5. CONCLUSIONS

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

1. The cut-out rescan and direct scan methods showed comparable trueness for all IOSs.

2. Groups PR and IS showed significant differences between the direct scan and cut-out rescan methods, while the other scanners showed similar precision.

3. The significant differences in linear distance measurements found at various coordinate points indicate that implant displacements are influenced by the scanning method.

4. Clinicians should carefully evaluate the characteristics of specific IOSs, scanning methods/workflows, and the clinical situations of individual patients to establish effective prosthetic plans that will ensure accurate occlusal records and optimal outcomes.

References

Abduo J, Elseyoufi M (2018). Accuracy of Intraoral Scanners: A Systematic Review of Influencing Factors. *Eur J Prosthodont Restor Dent* 26(3): 101-121.

Afrashtehfar KI, Alnakeb NA, Assery MKM (2022). Accuracy of Intraoral Scanners Versus Traditional Impressios: A Rapid Umbrella Review. *J Evid Based Dent Pract* 22(3): 101719.

Ahmed KE, Peres KG, Peres MA, Evans JL, Quaranta A, Burrow MF (2021). Operators matter - An assessment of the expectations, perceptions, and performance of dentists, postgraduate students, and dental prosthetist students using intraoral scanning. *J Dent* 105: 103572.

An S, Kim S, Choi H, Lee JH, Moon HS (2014). Evaluating the marginal fit of zirconia copings with digital impressions with an intraoral digital scanner. *J Prosthet Dent* 112(5): 1171-1175.

Braian M, Wennerberg A (2019). Trueness and precision of 5 intraoral scanners for scanning edentulous and dentate complete-arch mandibular casts: A comparative in vitro study. *J Prosthet Dent* 122(2): 129-136.e122.

Cao R, Zhang S, Li L, Qiu P, Xu H, Cao Y (2023). Accuracy of intraoral scanning versus conventional impressions for partial edentulous patients with maxillary defects. *Sci Rep* 13(1): 16773.

Carneiro Pereira AL, Souza Curinga MR, Melo Segundo HV, da Fonte Porto Carreiro A

(2023). Factors that influence the accuracy of intraoral scanning of total edentulous arches rehabilitated with multiple implants: A systematic review. *J Prosthet Dent* 129(6): 855-862.

Christensen GJ (2008). The challenge to conventional impressions. *J Am Dent Assoc* 139(3): 347-349.

Demirel M, Donmez MB, Şahmalı SM (2023). Trueness and precision of mandibular complete-arch implant scans when different data acquisition methods are used. *J Dent* 138: 104700.

Diker B, Tak Ö (2022). Accuracy of six intraoral scanners for scanning complete-arch and 4-unit fixed partial dentures: An in vitro study. *J Prosthet Dent* 128(2): 187-194.

Gómez-Polo M, Immorlano MG, Cascos-Sánchez R, Ortega R, Barmak AB, Kois JC, et al. (2023). 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: 104667.

Gupta S, Narayan AI, Balakrishnan D (2017). In Vitro Comparative Evaluation of Different Types of Impression Trays and Impression Materials on the Accuracy of Open Tray Implant Impressions: A Pilot Study. *Int J Dent* 2017: 6306530.

Jin G, Kim J-E, Nam N-E, Shin S-H, Shim J-S (2020). Accuracy improvement of intraoral scanning and buccal bite registration using healing abutment as landmarks: an in vitro study. *Applied Sciences* 11(1): 318.

Jin G, Shin SH, Shim JS, Lee KW, Kim JE (2022). Accuracy of 3D printed models and implant-analog positions according to the implant-analog-holder offset, inner structure, and printing layer thickness: an in-vitro study. *J Dent* 125: 104268.

Kakali L, Halazonetis DJ (2023). A novel method for testing accuracy of bite registration using intraoral scanners. *Korean J Orthod* 53(4): 254-263.

Kernen F, Brändle D, Wagendorf O, Recca M, Mehrhof J, Vach K, et al. (2023). Enhancing intraoral scanner accuracy using scan aid for multiple implants in the edentulous arch: An in vivo study. *Clin Oral Implants Res* 34(8): 793-801.

Kihara H, Hatakeyama W, Komine F, Takafuji K, Takahashi T, Yokota J, et al. (2020). Accuracy and practicality of intraoral scanner in dentistry: A literature review. *J Prosthodont Res* 64(2): 109-113.

Kim JE, Hong YS, Kang YJ, Kim JH, Shim JS (2019). Accuracy of Scanned Stock Abutments Using Different Intraoral Scanners: An In Vitro Study. *J Prosthodont* 28(7): 797-803.

Mangano F, Gandolfi A, Luongo G, Logozzo S (2017). Intraoral scanners in dentistry: a review of the current literature. *BMC Oral Health* 17(1): 149.

Mangano FG, Hauschild U, Veronesi G, Imburgia M, Mangano C, Admakin O (2019). Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: a comparative in vitro study. *BMC Oral Health* 19(1): 101.

Marques S, Ribeiro P, Falcão C, Lemos BF, Ríos-Carrasco B, Ríos-Santos JV, et al. (2021).

Digital Impressions in Implant Dentistry: A Literature Review. *Int J Environ Res Public Health* 18(3).

Murugesan A, Sivakumar A (2020). Comparison of accuracy of mesiodistal tooth measurements made in conventional study models and digital models obtained from intraoral scan and desktop scan of study models. *J Orthod* 47(2): 149-155.

Oh KC, Park JM, Moon HS (2020). Effects of Scanning Strategy and Scanner Type on the Accuracy of Intraoral Scans: A New Approach for Assessing the Accuracy of Scanned Data. *J Prosthodont* 29(6): 518-523.

Okamoto M, Tanabe N, Fukazawa S, Oyamada Y, Kondo H (2023). Accuracy of optical interocclusal registration using an intraoral scanner. *J Prosthodont Res* 67(4): 619-625.

Passos L, Meiga S, Brigagão V, Neumann M, Street A (2022). Digital impressions' accuracy through "cut-out-rescan" and "data exchange by over scanning" techniques in complete arches of two intraoral scanners and CAD/CAM software. *J Prosthodont Res* 66(3): 509-513.

Punj A, Bompolaki D, Garaicoa J (2017). Dental Impression Materials and Techniques. *Dent Clin North Am* 61(4): 779-796.

Reich S, Yatmaz B, Raith S (2021). Do "cut out-rescan" procedures have an impact on the accuracy of intraoral digital scans? *J Prosthet Dent* 125(1): 89-94.

Revilla-León M, Lanis A, Yilmaz B, Kois JC, Gallucci GO (2023a). Intraoral digital implant scans: Parameters to improve accuracy. *J Prosthodont* 32(S2): 150-164.

Revilla-León M, Sicilia E, Agustín-Panadero R, Gómez-Polo M, Kois JC (2023b). Clinical evaluation of the effects of cutting off, overlapping, and rescanning procedures on intraoral scanning accuracy. *J Prosthet Dent* 130(5): 746-754.

Rungrojwittayakul O, Kan JY, Shiozaki K, Swamidass RS, Goodacre BJ, Goodacre CJ, et al. (2020). Accuracy of 3D Printed Models Created by Two Technologies of Printers with Different Designs of Model Base. *J Prosthodont* 29(2): 124-128.

Saeed F, Muhammad N, Khan AS, Sharif F, Rahim A, Ahmad P, et al. (2020). Prosthodontics dental materials: From conventional to unconventional. *Mater Sci Eng C Mater Biol Appl* 106: 110167.

Sanda M, Miyoshi K, Baba K (2021). Trueness and precision of digital implant impressions by intraoral scanners: a literature review. *Int J Implant Dent* 7(1): 97.

Schmidt A, Klussmann L, Wöstmann B, Schlenz MA (2020). Accuracy of Digital and Conventional Full-Arch Impressions in Patients: An Update. *J Clin Med* 9(3).

Schott TC, Arsalan R, Weimer K (2019). Students' perspectives on the use of digital versus conventional dental impression techniques in orthodontics. *BMC Med Educ* 19(1): 81.

Shin SH, Doh RM, Lim JH, Kwon JS, Shim JS, Kim JE (2021). Evaluation of Dimensional Changes According to Aging Period and Postcuring Time of 3D-Printed Denture Base Prostheses: An In Vitro Study. *Materials (Basel)* 14(20).

Sultanoğlu EG, Eroğlu BK (2023). Evaluating the accuracy of intraoral scanners used in single-unit implant prosthesis construction. *International Dental Research* 13(S1): 32-37.

Yatmaz BB, Raith S, Reich S (2023). Accuracy of four recent intraoral scanners with respect to two different ceramic surfaces. *J Dent* 130: 104414.

Yun MJ, Jeon YC, Jeong CM, Huh JB (2017). Comparison of the fit of cast gold crowns fabricated from the digital and the conventional impression techniques. *J Adv Prosthodont* 9(1): 1-13.

Abstract in Korean

최종 임플란트 보철물 제작 과정에서 구강스캐너의 정확도: 컷아웃 재스캔과 직접 스캔 방법의 비교 분석

임플란트의 연조직 형태나 환자가 사용하는 임시 보철물의 형상을 기록하는 한 가지 방법으로, 구강 디지털 인상을 활용하여 임플란트 주변 부위를 컷아웃 재스캔 방법이 있다. 그러나, 이 방법으로 생성된 디지털 임플란트의 정밀도가 환자의 구강 해부학적 구조를 정확히 재현하는 데 있어 얼마나 신뢰할 수 있는지는 여전히 불확실하다. 따라서, 본 연구의 목적은 컷아웃 재스캔과 직접 스캔 방법을 비교하여 디지털 임플란트 인상의 정확도와 임플란트 위치 재현에 따른 선형 변위를 평가하는 것이다.

임플란트 모델은 다섯 가지 구강스캐너(IOSs)와 한 가지 실험실 스캐너로 각각 10회 스캔하였다. 이때, IOSs는 두 가지 스캔 방법(컷아웃 재스캔과 직접 스캔)을 사용하였다. 그 후, 각 IOS의 진실도(trueness)와 정밀도(precision), 임플란트 위치의 재현성을 평가하였다. 통계 분석은 유의수준 α = 0.05로 설정하여 일원분산분석(one-way ANOVA)를 사용하였다.

컷아웃 재스캔 방법을 사용할 때 각 IOS의 진실도는 직접 스캔 방법을 사용하였을 때와 유사하였다. 그러나, CEREC Primescan을 사용하는 경우 정밀도는 컷아웃 재스캔 방법에서 유의하게 낮은 결과를 보였다(직접 스캔: 18.92 ± 6.66 μm [평균 ± 표준편차], 컷아웃 재스캔: 34.40 ± 19.89 μm). IS 3800W에서도 유사한 결과가 관찰되었으며, 직접 스캔 방법에서는 19.38 ± 9.10 μm, 컷아웃 재스캔에서는 39.05 ± 19.93 μm으로 나타났다.

임플란트 위치 변위는 전반적으로 작았으나, TRIOS 3(F = 183.852, p < 0.001)

와 RAYiOS(F = 4.390, $p < 0.001$)를 사용하는 경우 컷아웃 재스캔 방식에서 유의한 수직 변위가 관찰되었다. 수평 차원의 임플란트 위치 변위는 대체로 작았지만, TRIOS 3와 RAYiOS를 사용할 때 컷아웃 재스캔 방법에서 상당한 수직 변위가 확인되었다. 특정 임상 사례에 적합한 보철 전략을 개발하기 위해 스캔 방법에 대한 신중한 평가가 필요하다.

핵심되는 말 : 구강스캐너, 임플란트 스캔바디, 진실도, 정밀도, 임플란트 변위