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RESEARCH AND EDUCATION

Effect of splinting scan bodies on the trueness of complete arch digital implant scans with 5 different intraoral scanners

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ABSTRACT

Statement of problem. The absence of fixed reference points can affect the trueness of complete arch intraoral digital implant scans. The effect of splinting intraoral scan bodies (ISBs) or the inclusion of artificial landmarks (AL) on the trueness of complete arch digital implant scans is still unclear.

Purpose. The purpose of this study was to analyze the effect of splinting ISBs or the inclusion of AL on the trueness of complete arch digital implant scans with 5 intraoral scanners (IOSs).

Material and methods. Six tissue-level dental implants (Straumann Tissue Level) were placed in an edentulous patient, and the correspondent definitive cast was digitized with a desktop scanner (IScan4D LS3i) to obtain the reference digital cast. Digital scans (n=10) were performed with 5 IOSs: TRIOS 4, Virtuo Vivo, Medit i700, iTero Element 5D, and Cerec Primescan. Three different scanning techniques were evaluated: conventional (cIOSs), splinted (sIOSs), and AL (AL-IOSs). The scan data obtained were imported into a metrology software program and superimposed to the reference digital cast by using a best-fit algorithm. The overall deviations of the positions of the ISBs were evaluated by using the root-mean-square (RMS) error (α=.05).

Results. The mean ±standard deviation trueness values for the cIOSs, sIOSs, and AL-IOSs groups were 48 ±8 μm, 53 ±7 μm, and 49 ±11 μm, respectively, with no statistically significant differences (*P*=.06). Significant differences were found for the IOSs used with each technique (*P*<.001). Primescan (27 ±4 μm cIOSs; 28 ±3 μm sIOSs; 31 ±3 μm AL-IOSs) showed significantly higher trueness than iTero 5D (47 ±5 μm cIOSs; 47 ±4 μm sIOSs; 50 ±6 μm AL-IOSs) (*P*=.002) and TRIOS 4 (93 ±18 μm cIOSs; 76 ±18 μm sIOSs; 107 ±13 μm AL-IOSs) (*P*=.001) for all techniques. In addition, no significant differences were found between the techniques by using iTero 5D or Primescan (*P*=.348 and *P*=.059, respectively).

Conclusions. The cIOSs, sIOSs, and AL-IOSs techniques showed similar trueness. The IOS used influenced the trueness of complete arch digital implant scans. (J Prosthet Dent 2024;132:204-210)

Accurate transfer of implant position is mandatory to obtain implant-fixed restorations with an adequate passive fit.[1] This transfer can be made by conventional methods by using an impression material and impressions copings or optical methods.[1] Despite the technique used, the correct transfer of each implant position is essential for the fabrication and fit of implant-supported prostheses and their subsequent long-term success.[2,3]

Digital scans have some advantages compared with conventional methods, such as avoiding laboratory steps, including the production of gypsum casts that could add deviation errors; the saving

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Clinical Implications

Splinting scan bodies or using artificial landmarks did not improve the trueness of complete arch implant intraoral digital scans. Therefore, clinicians should question the implementation of these techniques when obtaining a complete arch digital scan.

and storing of virtual casts in electronic databases that improve time efficiency and communication with patients, clinicians, and dental laboratory technicians; and the improvement in patient comfort and satisfaction.[4–6] However, accurate digital scanning of completely edentulous patients is challenging. Some authors reported greater accuracy for digital implant scanning,[7–10] whereas others concluded that conventional impressions had better results for complete arches.[11–14] The lack of anatomic reference points to be recognized by the intraoral scanner (IOS), the surface topography, and the surface characteristics of complete arches could be the major limitations.[12,15–17]

The conventional open-tray implant impression with splinted impression copings remains the standard in complete arch implant impressions, with reported high accuracy.[12,18,19] The main aim of splinting the impression copings is to avoid micromovement during the recording. Recently, a study[20] has also suggested that splinted intraoral scan bodies (ISBs) can improve complete arch scans by increasing the number of reference points.

In digital scans of edentulous arches, the common reference points are limited, which can cause incorrect stitching of the images or misinterpretation of parts of the scan as redundant data.[21] To overcome this limitation, different techniques to increase the number of reference points have been proposed.[20,22–28] However, the authors are unaware of studies that compared and evaluated the influence of these techniques on the accuracy of complete arch digital implant scans.

The main aim of this in vitro study was to compare the trueness of 3 different techniques for complete arch digital implant scans to create a protocol for a straightforward, rapid, and accurate fully digital workflow. The influence of the IOS system on each technique was also evaluated. The null hypotheses were that different scanning techniques would not affect the trueness of the scans and that the use of different IOS systems would not influence the trueness of the scanning technique.

MATERIAL AND METHODS

A definitive cast of an edentulous patient with 6 implant analogs (Tissue level implant analogs; Institut Straumann AG) distributed along the mandible at sites of the left first molar, left first premolar, left central incisor, right central incisor, right first premolar, and right first molar was used as a reference cast. The research received approval from the Ethics Committee for Health (CES-UCP) under reference number 201, granted on March 24, 2022.

Polyetheretherketone ISBs (Zirkonzahn White Scanmarker; Zirkonzahn GmbH) were used for the digital scans. They were tightened to 5 Ncm by using an automatic torque control unit (Endo-mate TC2; NSK) and were not moved between registrations to avoid positional errors. A desktop scanner (IScan4D LS3i; Imetric 4D) with an accuracy of ±5 μm for implant scans, according to the manufacturer, was used to scan the reference cast to obtain the digital reference cast.[29–31]

For the experimental groups, 3 different techniques were used according to their splinting conditions.[20,25,26] The conventional technique (cIOSs) was performed to scan the dental cast with the ISBs positioned and without additional references. The splinted technique (sIOSs) involved splinting the ISBs with orthodontic wire (Sentalloy; Dentsply Sirona) and resin (EZ - Pattern Lc; Hudens Bio Co).[20] The artificial landmark (AL) technique (AL-IOSs) consisted of attaching landmarks between ISBs on the keratinized mucosa of the alveolar ridge.[25,26] Radiopaque ball markers made from light-polymerized resin (EZ - Pattern Lc; Hudens Bio Co) were fixed with tissue adhesive (PeriAcryl Periodontal Tissue Adhesive; GluStitch Inc).

Five different IOSs were used with each technique: iTero Element 5D (Align Technology), TRIOS 4 (3Shape A/S), Cerec Primescan (Dentsply Sirona), i700 (Medit Corp), and Virtuo Vivo (Dental Wings). The scanning strategy applied for all the digital scans was the zig-zag technique, as used in previous studies,[32,33] starting from the most distal ISB of the fourth quadrant. A single operator (L.A.) with 5 years of experience using IOSs, after 3 training sessions of 20 minutes with each IOS performed all digital scans by using the most recent acquisition software program available for each IOS.

Sample size calculation was conducted by using a statistical software program (Bioestat 5.3; AnalystSoft Inc). The calculation was based on the results of a pilot study with the cIOS technique comparing 5 groups and assuming heteroscedasticity as determined by the Kruskal-Wallis test. Considering a minimum difference between groups of 46 μm (93 μm with TRIOS 4 versus 47 μm with iTero 5D), a pooled standard deviation of 18 μm, alpha of 5% and power of 95%, a sample size of n=6 per group was determined. To adjust for possible losses and to be consistent with previous studies,[7,29,34–36] a sample size of 10 per group was used. All digital scans were performed in the same room with controlled illumination (1000 lux and 4100 K), determined with a light meter (EM2243 Light Meter; Faithfull Tools).[37,38] Before

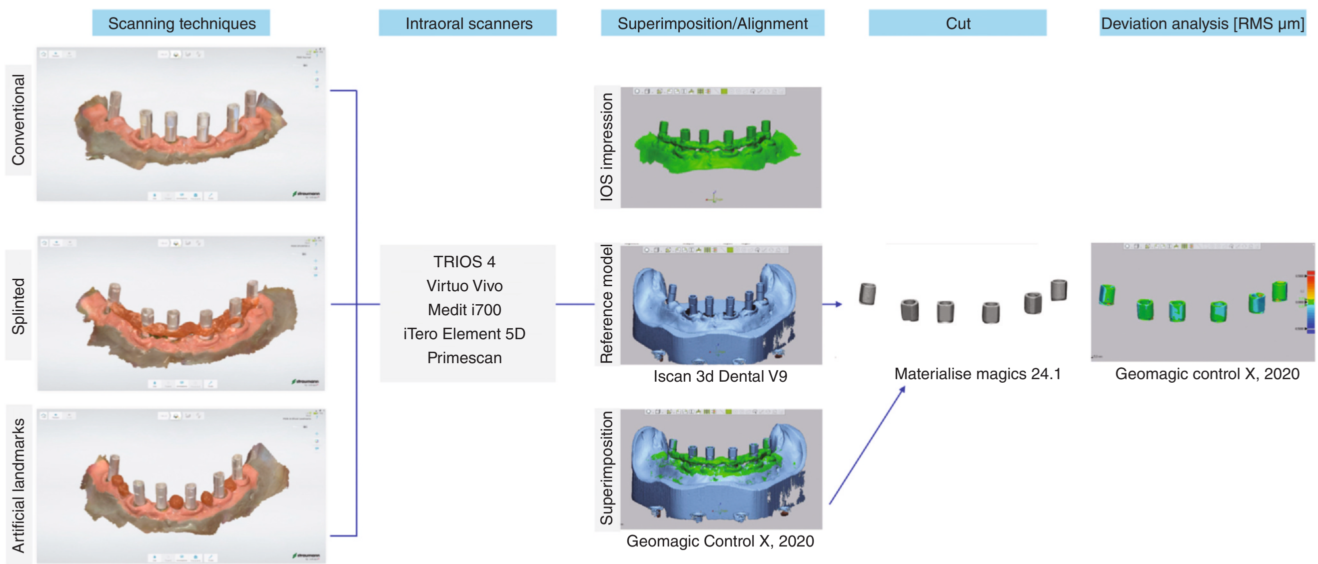

Figure 1. Three-dimensional analysis overview of technique comparisons with intraoral scanners (IOSs) and reference digital cast.

each digital scan, the scanner was calibrated according to the manufacturer's recommendations. When errors such as artifacts, overlaps, or evident distortions occurred while capturing an image, it was recaptured.

The standard tessellation language (STL) files from both the IOSs and the desktop scanner were imported into a software program (Geomagic Control X 2020; 3D Systems Inc) to compare and analyze the deviation (trueness) resulting from superimposing the casts. The reference digital cast was used as the reference. Subsequently, the surfaces of the STL files were precisely aligned for optimal superimposition by using the "Align Between Measured Data" and "Best-Fit Alignment" functions. The "Best-Fit Alignment" was performed with the "Use Select Data Only" option, selecting everything except the ISBs, to prevent them from affecting the alignment and subsequent evaluation. To obtain the most precise root-mean-square (RMS) error value, all the STL files were superimposed, and an additional software program (Materialise Magics 24.1; Materialise) was used to simultaneously cut them within the same scan region, excluding the body, the base, and the remaining cast (Fig. 1). The overall deviation was assessed by using the "3D Compare" function, which generated a color map of the superimposed digital casts to quantitatively analyze the 3-dimensional (3D) changes. The color map ranged from +0.5 mm to −0.5 mm, with a tolerance range of ±0.05 mm. The mean RMS error indicated the deviation value (trueness). The RMS is a mathematical parameter that measures the size of a dataset. The RMS values are calculated by taking the square root of the average of the squared differences between the corresponding points on the 2 digital casts.

The main dependent outcome was the trueness of each technique tested, measured in µm. Trueness assessed how close the digitized test object (ISBs) was to the true dimensions of the reference digital cast.

Descriptive statistics, including mean, median, SD, interquartile range (IQR), minimum, and maximum were used to analyze the data. The normality of the data set was assessed by using the Shapiro-Wilk test. Where normality was confirmed, a 2-way ANOVA was used to analyze the differences between techniques with the same IOS and between IOSs with the same technique, as well as their interaction effect. The post hoc Tukey range test was used to identify significant differences between the groups. In cases where normality was absent, the Kruskal-Wallis test was used, followed by the pairwise comparison method with Bonferroni correction (α=.05). A statistical software package (IBM SPSS Statistics, v29.0; IBM Corp) was used to analyze the data.

RESULTS

A comparison was made between the overall trueness of different digital scan techniques, independent of the IOS used. The sample was not normally distributed according to the Shapiro-Wilk test (P>.05). The results indicated that the cIOSs technique showed greater trueness (47 ±27 µm) than the sIOSs (49 ±17 µm) and AL-IOSs (55 ±30 µm) digital scan techniques, regardless of the type of IOS used. However, the Kruskal-Wallis test revealed no statistically significant differences in the scanning techniques (P=.06).

The Kruskal-Wallis test was used to evaluate the influence of different IOSs on various digital scan techniques, and the results indicated significant differences among the IOSs (P<.001) (Table 1). The pairwise comparison method with Bonferroni correction revealed that Primescan (27 ±4 µm; 28 ±3 µm; 31 ±3 µm) demonstrated significantly higher trueness than iTero 5D (47 ±5 µm; 47 ±4 µm; 50 ±6 µm) (*P*=.002) and TRIOS 4 (93 ±18 µm; 76 ±18 µm; 107 ±13 µm) (*P*=.001) across all 3 digital scan techniques (cIOSs, sIOSs, and AL-IOSs, respectively). Additionally, Virtuo Vivo (27 ±6 µm; 47 ±10 µm; 42 ±8 µm) showed significantly higher trueness than iTero 5D (*P*=.007) with the c-IOSs technique, and Primescan had significantly higher trueness than Medit i700 (38 ±3 µm; 45 ±5 µm; 40 ±4 µm) (*P*=.037) and Virtuo Vivo (*P*=.005) with the sIOSs technique. Conversely, TRIOS 4 had significantly lower trueness than Virtuo Vivo (*P*=.001, *P*=.016, and *P*=.003) and Medit i700 (*P*=.042, *P*=.029, *P*=.003) across all techniques.

Comparing the different techniques by using the same IOSs system, the Kruskal-Wallis test revealed statistically significant differences (*P*<.05) between digital scan techniques for the IOSs tested, except for iTero 5D (*P*=.348) and Primescan (*P*=.059) (Table 1, Fig. 2). The pairwise comparison method with Bonferroni correction showed that TRIOS 4 with the sIOSs technique had significantly higher trueness than with the AL-IOSs technique (*P*=.003). In addition, the results demonstrated statistically significant higher trueness between the cIOSs technique and the other groups for Virtuo Vivo (s-IOSs: *P*=.001; AL-IOSs: *P*=.012). Also, Medit i700 had statistically significant higher trueness with the cIOSs technique compared with the sIOSs technique (*P*=.010).

DISCUSSION

The present study analyzed the trueness of 3 different intraoral scanning techniques by using different IOSs. The null hypothesis that different scanning techniques would not affect the trueness of the scans was not rejected, since there were no significant differences, although different scanning techniques affected the trueness of the digital scans. The second null hypothesis, that the use of different IOS systems would not influence the trueness of the scanning technique, was also rejected.

The techniques compared in this study were intended to solve the limitations and difficulties involved in the digital scanning of edentulous patients with implants. Regarding the conventional impression method, the literature has not been consistent. Some authors have reported that the conventional impression method is still recommended for long-span areas,[11,12,14] whereas others have reported that the accuracy of digital scans is similar to that of conventional impression making.[7–10] In this study, the results obtained with digital scans were within a clinically acceptable threshold (up to 200 µm).[10,39]

Table 1. Mean, median, SD, IQR, minimum, and maximum trueness values of different techniques for each IOS (µm)

IOSs	cIOSs					sIOSs					AL-IOSs					
	Mean	Median	SD	IQR	Min-Max	Mean	Median	SD	IQR	Min-Max	Mean	Median	SD	IQR	Min-Max	*P*
TRIOS 4	93[a]	94	18	27	63-116	76[a]	74	18	22	48-105	107[a]	107	13	16	86-123	**.004**
Virtuo Vivo	29[b]	27	5	6	23-38	49[a,b]	47	6	10	39-58	45[b]	42	14	8	32-79	**.001**
Medit i700	41[b,c]	38	7	3	35-58	47[b,c]	45	5	5	43-58	42[b,c]	40	4	5	38-49	**.011**
iTero 5D	47[a,c]	46	5	3	39-57	47[a,b,c]	47	4	5	39-52	50[a,b,c,d]	52	6	10	42-58	.348
Primescan	27[b]	27	4	7	22-34	28[d]	28	3	4	25-33	31[b,c]	30	3	5	28-36	.059
P	**.01**					**.01**					**.01**					

AL-IOSs, artificial landmarks digital scan technique; cIOS, conventional digital scan technique; IQR, interquartile range; Min, minimum; Max, maximum; SD, standard deviation; sIOSs, splinted digital scan technique.

Kruskal-Wallis test used for intergroup comparisons; same letter defines no significant difference (*P*>.05). Values in bold indicate statistically significant differences (*P*<.05).

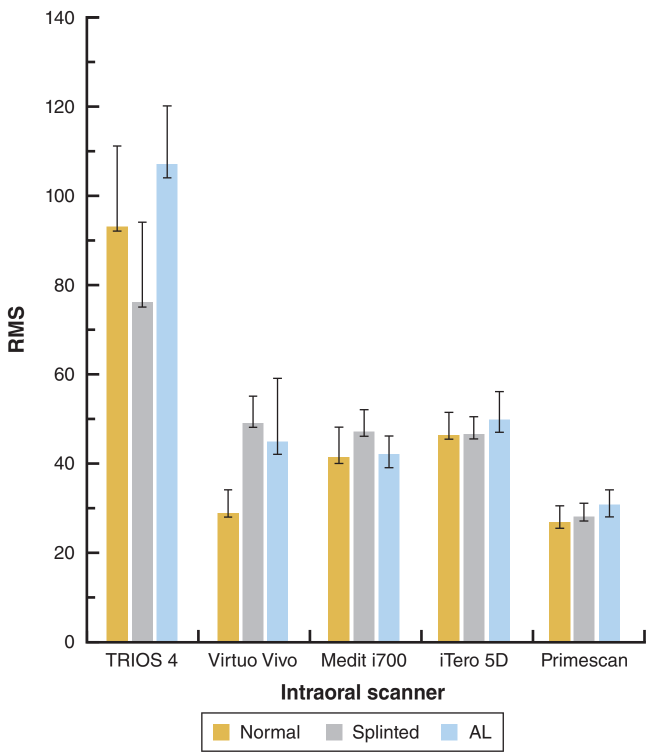

Figure 2. Mean root-mean-square (RMS) and standard deviation (SD) results for each digital scan technique evaluated, accordingly with each intraoral scanner (IOS). AL, artificial landmark.

A technique involving the addition of landmarks to the edentulous space to increase the number of reference points has been evaluated.[22,25,26] Chochlidakis et al[26] reported a 3D-deviation of 162 μm between the casts generated from the complete arch digital scan and conventional impressions. However, in the current study, the digital scans were compared with a reference digital cast, making direct comparisons of the outcomes impossible.

Edentulous patients lack intraoral characteristics for stitching. Therefore, splinting ISBs should be helpful for digital implant scanning. Cappare et al[20] reported, based on an in vivo study, that digital scans with splinted ISBs were a reliable alternative to the conventional workflow for implant-supported complete arch prostheses. They added that the digital workflow seemed to be a valid option because it is time-saving and less unpleasant for patients.[20] Huang et al[27] also compared the accuracy of an original ISB and a new design with an extensional structure, similar to the splinted technique. This extension aimed to increase the number of reference points and obtain images with every scan based on the rigid structures instead of the smooth, reflective, and movable mucosa, thus minimizing the errors during the stitching process.[27] The authors showed that this new ISB exhibited the highest accuracy among the groups of digital scans.[27] In the present study, the sIOSs technique has statistically similar trueness to that of the other techniques. In contrast, Mizumoto et al[28] reported that splinting ISBs were associated with the highest distance deviation. They suggested that splinting the ISBs to improve the stitching process did not improve accuracy.[28] A possible explanation for these results could be the material used for the splinting, since Mizumoto et al[28] used dental floss, whose color and thickness could cause difficulties for the IOS. These results contradict the conclusions drawn by Retana et al,[40] who reported that splinting ISBs can enhance the accuracy of complete arch digital implant scans by improving the morphological landmarks through the stitching process. These authors used 3D printed bars with random textures on one side as a method to splint the ISBs. The inclusion of bars with random textures could enhance the stitching process of the scan bodies, as it helps prevent uniformity and reduces the likelihood of the IOS erroneously identifying one ISB as another.

Previous research has indicated that an increase in the distance between ISBs reduces the trueness of IOSs.[41] The reduced trueness has been primarily attributed to the requirement for more alignments to generate a 3D representation, and the absence of reference points between ISBs hampers the efficiency of image stitching. In the current study, no statistically significant differences were observed among the different scanning techniques, possibly because of the closer proximity of the implants, where splinting ISBs might not significantly influence the trueness of the scans. Moreover, the size of the scanning head is also believed to play a role in the results. Previous studies[42,43] have suggested that larger scanning head sizes provide higher accuracy than smaller ones. Notably, the Primescan and iTero 5D IOS have larger scanning heads compared with those of other IOSs, enabling them to capture a broader area. Consequently, when using these IOSs, the use of splinting ISBs may not substantially affect the trueness of the scans.

The interaction between scanning techniques and IOSs was analyzed to determine whether the effect of scanning techniques on the trueness of complete arch scans was dependent on the type of IOS used and vice versa. The analysis revealed a significant interaction between scanning techniques and IOS (P=.01), suggesting that the impact of one factor on the trueness of scans may vary depending on the level of the other factor. Thus, considering the interaction effect is crucial when selecting a scanning technique or an IOS for a specific clinical scenario.

Although the scanning protocol was the same for all measurements, the evidence about the trueness of the different scanning protocols for completely edentulous patients is limited. The zig-zag technique was used for scanning, which may be well-suited for certain IOSs while potentially posing challenges for others. Despite the lack of specific guidance from published articles or manufacturers on the optimal scanning strategy for complete arch implant scans, the authors applied the same protocol across all IOSs analyzed. To reduce the risks associated with operator experience, all scans were performed by the same operator under the same environmental conditions. Finally, the present study only focused on the data-acquisition step of the digital workflow and did not evaluate the effects on the definitive restoration.

The assessment approach used in this study has been well documented by studies by using similar methods.[7,44–46] Cakmak et al,[47] investigating the impact of 3D analysis software program and operator variability on the measurements of implant scans, reported that most software programs yielded similar results, except for one, regardless of the operator. The overall interoperator reliability with the tested 3D analysis software program was high. These results suggest that the choice of software program for 3D evaluation has minimal influence and that different software programs and operators can produce similar results.

Limitations of this research included the in vitro experimental design, the zig-zag scanning protocol, and the different IOS technologies used by each IOS. Furthermore, the research methodology did not encompass the computer-aided design (CAD) process involving alignment between the digital scan's implant scan body and the CAD library's implant scan body, and it did not address the manufacturing procedures (whether additive or subtractive methods) for fabricating complete arch implant-supported prostheses. As a result, it is possible that higher discrepancies could arise during the fabrication of implant-supported prostheses.

Additional research is needed to develop a reliable technique that can be easily applied by dentists when performing complete arch digital scans. After evaluating the most accurate technique in a preclinical setting, in vivo research is recommended to test its application in a clinical setting. The integration of technology should help both dentists and dental technicians achieve better clinical outcomes without escalating the cost-benefit ratio. This integration should be based on evidence-based information accompanied by an implementation plan that ensures a swift learning curve for practitioners and seamless integration into the dental practice environment.

CONCLUSIONS

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

1. The cIOSs, sIOSs, and AL-IOSs techniques showed similar trueness results.
2. The scanning system had a significant influence on the scan trueness results. Primescan resulted in higher trueness ($P<.01$) than Medit i700, iTero 5D, and TRIOS 4 with all techniques.
3. Splinting ISBs or using the AL-IOSs technique did not affect the trueness of the digital scans with Virtuo Vivo, Medit i700, and Primescan. However, with TRIOS 4, splinting ISBs improved the trueness of the complete arch digital implant scans.

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