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Original article

Accuracy of intraoral scanners based on jaw curve and inter-implant distance

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ABSTRACT

Background: *In digital dentistry, the intraoral scanner (IOS) is the primary data-collecting device. The data must be accurate to prevent undesirable stresses and technological difficulties resulting from prosthetic misfits. The span length of restorations influences the accuracy of IOS impressions.* ***Purpose:*** *This research aimed to compare the accuracy of virtual models scanned by different IOSs to determine whether jaw curvature and inter-implant distance affect accuracy.* ***Methods:*** *Four mandibular edentulous models were prepared by replacing the site of the missing tooth with an implant. The prepared holes were drilled at 7mm, 14mm, 21mm, and 28mm. Five scans for each model were taken with a desktop laboratory scanner as a reference model and with Trios3Shape and 3Disc Heron IOSs to evaluate trueness and precision (T&P). The scans were saved as standard triangulation language files and statistically analyzed at a level of significance ($P \leq 0.05$).* ***Results:*** *There was a significant difference between the IOSs in inter-implant distances ($P < 0.05$). The greatest distortion was reported in the 21mm and 28mm groups for both scanners ($P \leq 0.05$), while the lowest distortion was observed in the 7mm and 14mm groups for the Trios3Shape scanner.* ***Conclusion:*** *Jaw curvature and inter-implant distance impacted the accuracy of the IOS. Distortion and reduced reproducibility of T&P increased with jaw curve and inter-implant distance. The Trios3Shape IOS showed maximum accuracy at 7mm and 14mm inter-implant distances, while the 3Disc Heron IOS produced significant distortion of trueness at 21mm and 28mm inter-implant distances.*

Keywords: *implant; intraoral scanners; jaw curve; precision; trueness*
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INTRODUCTION

The wide use of digital technology in dental practices, especially in dental prosthodontics, has led to the gradual replacement of conventional impression techniques with digital dental technology.[1] An essential step in the prosthetic workflow is an accurate impression. Data collection must be precise to prevent undesirable stresses and technological difficulties resulting from prosthetic misfits. To avoid active stress on implants, a passive fit of prosthetics is essential. Some research studies have reported that misfits can range from 22 to 100µm.[2] Therefore, accurate digital data collection is required for the passive fit of implant-supported prostheses in the digital workflow; otherwise, active force on the implant system can result in biological and prosthetic failures.[3]

In the mid-1980s, intraoral scanners (IOSs) were introduced in dentistry as tools for data collection in digital dentistry. Similar to conventional intraoral impressions, IOSs create a mirror image of oral structures in the form of three-dimensional (3D) virtual models, eliminating the need for conventional impressions and physical model fabrication. Digital implant impression images can be produced using either direct or indirect digitization.[4–12]

A scan body implant (SBI) and an IOS collaborate in the direct method of implant digital impressions. The dental implant analog is attached to the SBI, which is then scanned. The image of the implant SBI is imported into CAD software, where it serves as a transfer tool to combine the dental implant intraorally with the virtual location of the implant within the digitizing program, and the digital image is superimposed.[13,14]

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Superimposition is often achieved by matching a reference scan model acquired by scanning the model in a desktop scanner as a reference mesh and then superimposing the meshes (virtual models) from the digital scan test groups onto the resultant standard triangulation language (STL) file. Based on the virtual implant's 3D position, scanned abutments enable dental professionals to design and complete the final implant-supported prosthesis without the use of an impression or a stone cast. The impression or final gypsum cast is scanned using a desktop scanner as the indirect method of the digital impression procedure to create a digital image.[15–18]

Several researchers reported greater accuracy, higher patient satisfaction, and less time consumption using digital implant impressions, while other studies showed superior results with the conventional implant impression method compared to the digital impression method.[10,12] The shape and margin of tooth preparation, the number of teeth or implants scanned, the curve of the jaw, the span of the edentulous area, moisture in the scanned area, the presence of blood or saliva, the effectiveness of scanning systems, patient movement, and the operator's skill are all factors that affect the accuracy of scanned models.[9,17,19,20]

The accuracy of scanned models is significantly influenced by the span length of the edentulous area. Numerous studies on digital impression technology have reported that the accuracy of scanned data increases with shorter span lengths of implant-supported prostheses, whereas longer spans reveal minimal accuracy.[17,19] However, there has been little emphasis on the effect of the length of the edentulous span, curvature of the jaw, and inter-implant distance on the accuracy of IOSs.

Accuracy is frequently referred to as trueness and precision (T&P), according to the International Organization for Standardization. Trueness is defined as "the proximity between the test object and the reference object" and precision is defined as "the variability of repeated measurements of the object."[21] To provide a trustworthy and reproducible scan image, the ideal IOS equipment should possess outstanding T&P.[22] The null hypothesis was that there are no differences in T&P when using a desktop scanner and IOSs and that jaw curvature with different inter-implant distances does not affect the accuracy of virtual implants scanned by different IOSs. The objective of the current study was to assess and compare the accuracy of virtual models scanned by two IOSs to determine whether jaw curvature and inter-implant distance affect accuracy.

MATERIALS AND METHODS

Four plastic mandibular fully edentulous standard models were used, and an experimental workflow is illustrated in Figure 1. The models were prepared using a one-piece implant (IMPLANT SYSTEM KOS®, Beograd, Serbia) to simulate an implant-supported fixed prosthesis as follows: Model 1: Dental implant installation at the site of the mandibular left central incisor (31) and mandibular canine (33). Model 2: Dental implant installation at the site of the left mandibular central incisor (31) and mandibular first premolar (34). Model 3: Dental implant installation at the site of the left mandibular central incisor (31), mandibular canine (33), and mandibular first molar (36). Model 4: Dental implant installation at the site of the left mandibular central incisor (31), mandibular first premolar (34), and mandibular second molar (37).

The centers of each of the parallel cylindrical holes, which were spaced 7mm apart, were prepared for implant installation. Using a digital vernier caliper, the consistent distance between the centers of the two implants was confirmed to be 7mm. The prepared holes in models 1, 2, 3, and 4 were drilled at 7mm, 14mm, 21mm, and 28mm for the left mandibular central incisor (31), canine (33), first premolar (34), first molar (36), and second molar (37), respectively.

Each model was scanned using a desktop blue light laboratory scanner (E1; 3Shape, Denmark) to create a digital reference dataset. For models 1, 2, 3, and 4, this reference dataset was then saved in STL file format.

The four test models were scanned using two IOSs: TRIOS™ (3Shape, Denmark) and 3DISC Heron™ (HERON SCAN 3.1, IOS Intraoral Color Impression

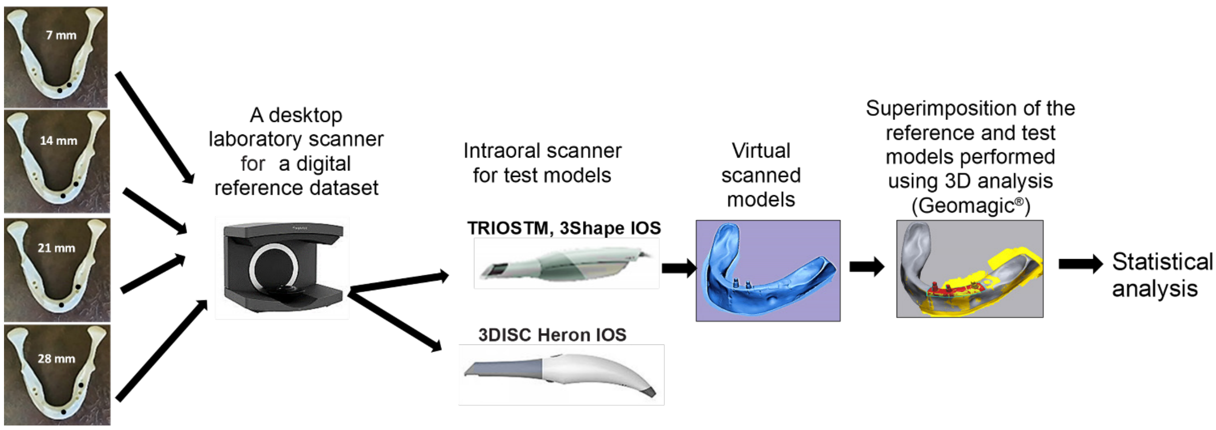

Figure 1. An experimental workflow.

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Scanner, USA). Both scanners operate based on confocal microscopy principles. For scanning the lower dental arch, the manufacturer recommends three swipes—occlusal, buccal, and lingual—to ensure complete data coverage of all necessary surfaces. The scanning was performed by the same person, following the manufacturer's instructions.

The prepared model was scanned five times using a desktop scanner and two IOSs to evaluate the accuracy of each scanned model by examining both T&P. Each scanner was calibrated before each scanning session according to the recommended protocol. Each model was trimmed and processed using a mesh mixer to limit the measurement area. Primary scanning was performed first, and target areas were marked in green for rescanning to obtain high-definition scans and detect any missed or unclear spots for adaptive scanning. A color-coded map illustrated the differences between the desktop scanner (the reference model) and the IOS (the tested model). Green and red colors denote surfaces that are precisely aligned, while blue indicates that the test model surface was negatively positioned relative to the reference model (Figure 2).

The scanned models were superimposed to examine deviations. Irrelevant areas beyond the field of interest were eliminated to ensure precise superimposition. A repeated best-fit algorithm was used to individually align the STL datasets of the scanned models with the reference dataset for trueness measurement. Part alignment was performed to achieve perfect implant matching based on the implant's constructed plane. After aligning the surfaces, the absolute volumetric deviations between the reference and the tested model were calculated. For precision measurements, five scans were superimposed on each other within each scanning pathway (n = 10). Superimposition of the reference and test models was performed using 3D analysis (Geomagic® Control™ software, USA).

The virtual reference model STL file was imported into the program and used as the reference data. The STL file of the virtual model from the sample group was imported as the measured data. Only selected points in the designated area were compared in 3D to eliminate variations outside the area of interest, which is clinically significant. A color map with 20 color components depicting visual deviation was created (Figure 3). After generating the report, the statistical analysis data and color map information were exported (Figure 3). The root mean square error (RMSE) values were calculated to measure the deviation between the reference model and scan files, assessing trueness. The 3D dataset of scan files within each group was analyzed for RMSE. Results were statistically analyzed using SPSS software version 19 (IBM, Chicago, USA). Data were

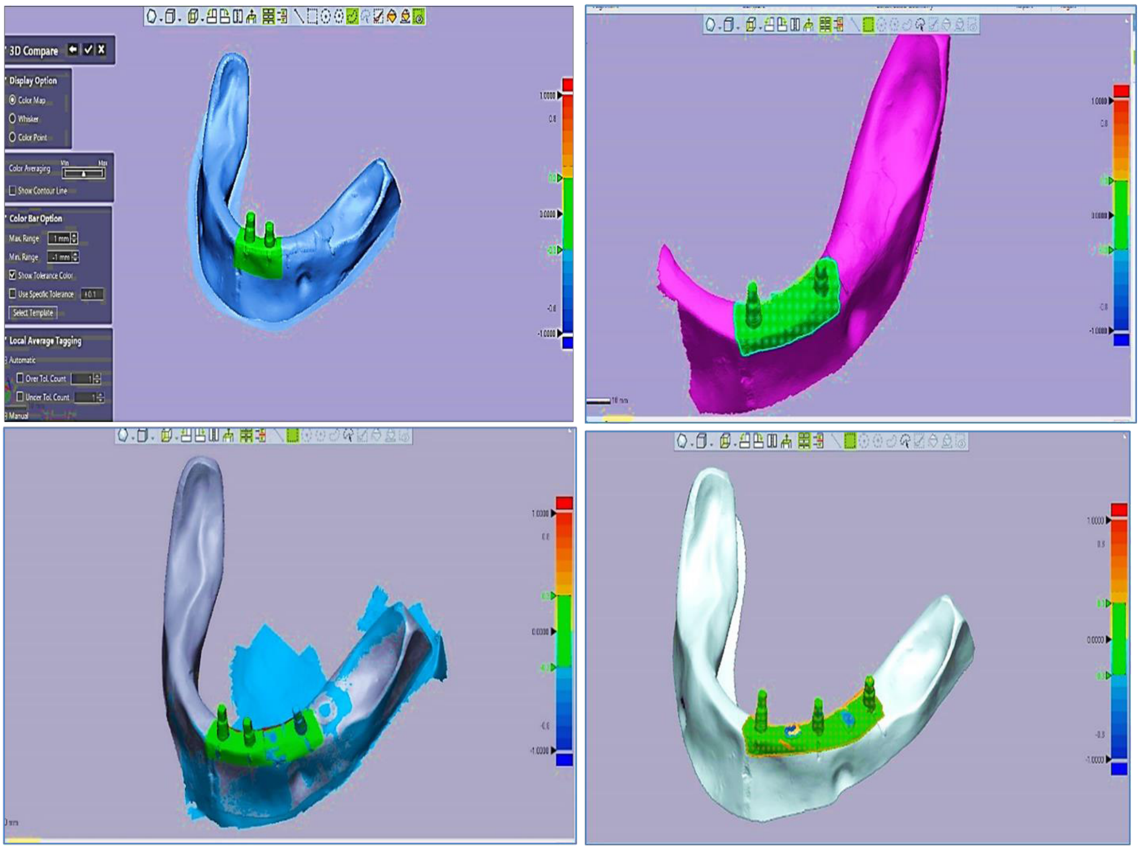

Figure 2. Virtual scanned models. The green area represents the target area for best-fit alignment and 3D comparison with the measured model in each group, where the distance between the centers of the two implants is consistent at 7 mm. A. Model 1 with a 7mm inter-implant distance. B. Model 2 with a 14mm inter-implant distance. C. Model 3 with a 21mm inter-implant distance. D. Model 4 with a 28mm inter-implant distance.

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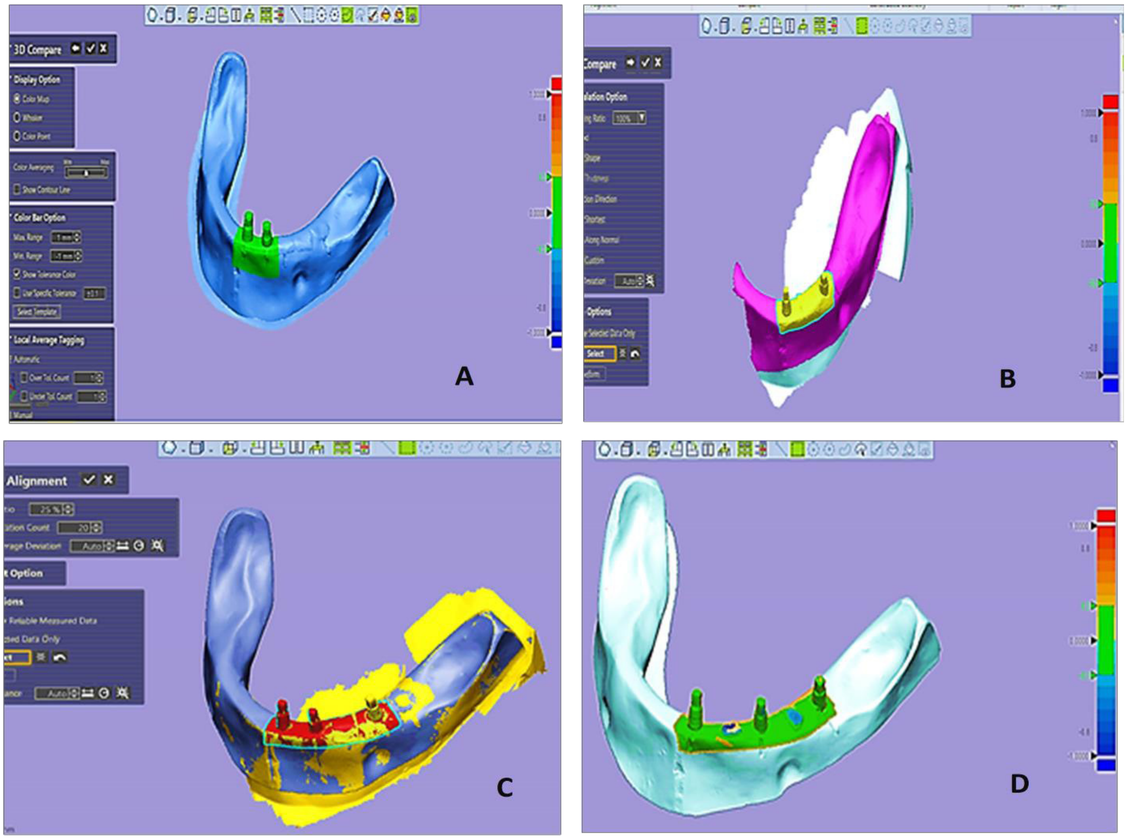

Figure 3. 3D analysis program report. A. Model 1. B. Model 2. C. Model 3. D. Model 4. Superimposition of the scanned models obtained from Trios3Shape and 3Disc IOS with the virtual reference model.

Table 1. Mean (Min, Max) in micrometer (μm) of precision and trueness for the Trios3Shape and 3Disc Heron Intraoral scanners

Scanner	Type	Model	Mean	Minimum	Maximum	N
3Shape Group	Precision	MODEL1	0.025	0.0013	0.0590	5
		MODEL2	0.037	0.0322	0.0393	5
		MODEL3	0.039	0.0346	0.0443	5
		MODEL4	0.019	0.0008	0.0358	5
	Trueness	MODEL1	0.011	0.0110	0.0210	5
		MODEL2	0.021	0.0101	0.0310	5
		MODEL3	0.041	0.0310	0.0500	5
		MODEL4	0.021	0.0110	0.0300	5
3Disc Group	Precision	MODEL1	0.029	0.0117	0.0527	5
		MODEL2	0.019	0.0021	0.0308	5
		MODEL3	0.023	0.0046	0.0208	5
		MODEL4	0.032	0.0245	0.0509	5
	Trueness	MODEL1	0.013	0.0110	0.0140	5
		MODEL2	0.012	0.0100	0.0140	5
		MODEL3	0.013	0.0120	0.0150	5
		MODEL4	0.058	0.0450	0.0600	5

N = Number of samples

Table 2. Shapiro-Wilk test for the Trios3Shape and 3Disc Heron intraoral scanners

Model	Scanner	Tests of Normality Shapiro-Wilk		
		Statistic	df	Sig.
MODEL1	3Shape Group	.938	5	.652
	3Disc Group	.584	5	.000*
MODEL2	3Shape Group	.778	5	.053
	3Disc Group	.757	5	.034*
MODEL3	3Shape Group	.948	5	.722
	3Disc Group	.979	5	.928
MODEL4	3Shape Group	.883	5	.324
	3Disc Group	.909	5	.464

Statistically significant differences among the scanners ($P \leq 0.05$)

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checked for normality of distribution and homogeneity of variance using the Shapiro-Wilk test. Pairwise comparisons were conducted using the Mann-Whitney U test, and the independent samples t-test was used to detect differences in trueness and precision between different IOSs.

RESULTS

The average deviation from the reference scanned models in the 3D comparison was assessed between the reference models obtained by the desktop scanning device and those obtained using the Trios3Shape and 3Disc Heron IOSs. The sample size (n = 15) included approximately five samples for each scanned model.

The analyzed data on T&P among inter-implant distance values for the two IOSs are listed in Table 1. The T&P of the scanned models showed significant differences among the IOSs.

The analyzed data, including the median trueness, mean precision, and P values for the interaction between scanners, are listed in Table 2. For the 3Disc IOS, the trueness of Model 1 and Model 2 at 14mm and 21mm inter-implant distances, respectively, revealed significant differences ($P \leq 0.05$). There was no significant difference in inter-implant distances for Model 1, Model 2, Model 3, and Model 4 with the Trios3Shape IOS ($P > 0.05$) (see Table 2).

When the two IOSs, Trios3Shape and 3Disc Heron, were examined for the same scanned model, there was no significant difference between the IOSs for model 1 at a 7mm inter-implant distance ($P > 0.05$) (see Table 3). However, significant differences were observed for models 2, 3, and 4 (see Tables 3 and 4). The top outcomes for T&P, represented by visual color maps from each device, are shown in Figure 4.

Table 3. Independent-samples Mann-Whitney U test for models 1 and 2

Model	Scanner	N	P-value
MODEL1	3Shape Group	5	.151
	3Disc Group	5	
MODEL2	3Shape Group	5	.008*
	3Disc Group	5	

N = number of samples; statistically significant differences among the scanners ($P \leq 0.05$)

Table 4. Independent samples t-test for models 3 and 4

Model	Scanner	t	df	P-value
MODEL3	3Shape Group 3Disc Group	8.272	8	.000*
MODEL4	3Shape Group 3Disc Group	-2.102	8	.005*

Statistically significant differences among the scanners ($P \leq 0.05$)

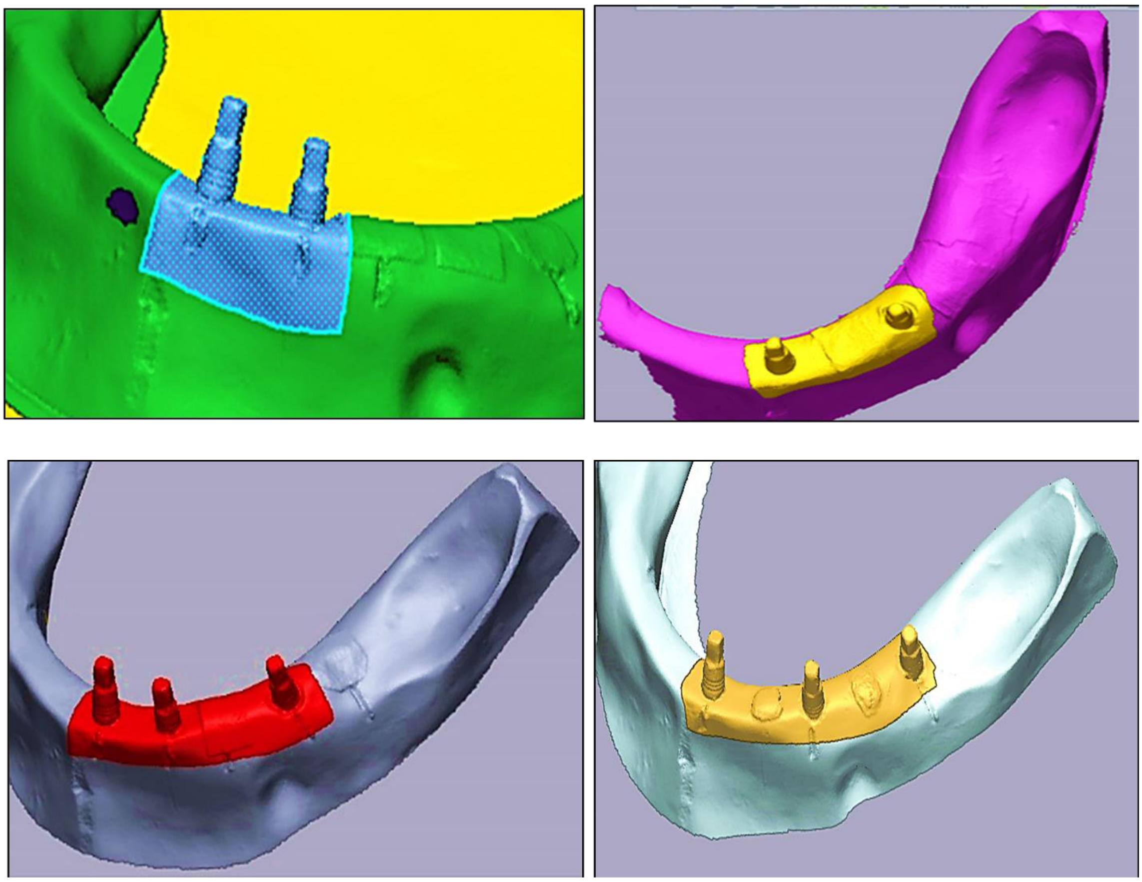

Figure 4. Visual color map representation.

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DISCUSSION

The current study was designed to evaluate whether jaw curvature and inter-implant distance affect the accuracy of 3D models produced by two IOSs at various inter-implant distances. Based on the study's findings, the null hypothesis—that there are no significant accuracy differences between the two IOSs—was partially rejected. Additionally, the hypothesis that the distance between implants and jaw curvature does not affect accuracy was rejected.

Achieving a well-fitting prosthesis is challenging but essential to prevent problems and ensure the durability of the prosthetic construction. A prosthesis made with an IOS is generally more accurate than one made with traditional cast frames. The accuracy of IOSs is affected by the amount of edentulous space between implants.[24,25] For digital impressions, many studies have reported that shorter spans of implant-supported prostheses are associated with greater accuracy in observed intraoral scan data, whereas longer spans show lower accuracy.[23,24] The accuracy of scanning a short span for an implant-supported prosthesis is reportedly comparable to the conventional impression technique, while digital scanning tends to produce less accurate results for longer spans.[8,23–26]

Every IOS has a scan protocol specified in the manufacturer's instructions, but it often does not indicate where to start the scan, which can be problematic, especially when scanning both quadrants. The accuracy may vary between the areas where the scan begins and ends, as the stitching method can introduce cumulative errors as the scan progresses from the start to the proximal region.[27] The trueness error in this study falls within the permitted range for passive fitting, except for the 28mm scan model, where the error exceeds 22µm. For trueness, a mismatch of at least 22µm is considered significant.[2,28]

When comparing trueness among IOSs, significant statistical differences were observed between the 3Disc and 3Shape IOS groups for models 1 and 2. However, the difference in errors was limited to 20µm. Precision data showed increased inaccuracy with longer edentulous spans. In this investigation, models 3 and 4, which had larger inter-implant distances, particularly with the 3Shape IOS, exhibited increased precision errors. The inaccuracy grew with the 21mm and 28mm increases in distance. These findings are consistent with other research.[17,25]

Although the authors used inter-implant distances of 21mm and 28mm—considered long in clinical practice—they did so to compare the effects of different edentulous span lengths between the chosen implants. One factor influencing scanning error could be the jaw curve from the anterior to the posterior region.[9,19,20] The authors suggested measuring the error caused by the curved span. Consequently, implants were placed from the anterior to the lower posterior region, where the arch is notably curved. This placement demonstrates the test objects' translation inaccuracies compared to the reference object, which affects the outcome estimation and is likely due to the stitching procedure.[25,29]

The size of the scanner's tip is a crucial factor in determining accuracy in clinical practice, particularly for target objects placed in confined locations, such as the distal part of the jaw. A smaller scanner head is more likely to maintain a clear line of sight for light throughout the scanning process. However, a larger scanner head generally improves T&P compared to a smaller head. This is because a larger head requires fewer images to be stitched together, reducing the potential for errors associated with stitching more images, as is necessary with a smaller head.[30,31]

The alignment of data, or superimposition of test and reference models, is another crucial aspect of measuring accuracy. Correct model alignment reveals translation inaccuracies between the test and reference objects, which affects the software's result estimation. Since local best-fit alignment and best-fit alignment methods produced fewer alignment errors,[28] it is suggested to use a small portion of the scanned models for accurate alignment. This approach is supported by research studies that focused on the area of interest after trimming the scanned data to enhance the accuracy of model alignment.[20,32,33]

Since this study is an *in vitro* design, the data may differ from those obtained in actual patient scenarios, where intraoral scanning is influenced by complex factors, such as tongue movement, ambient temperature, humidity, and lighting. Therefore, further research is needed to examine various IOSs and scan bodies, followed by comparable *in vivo* experiments.

In conclusion, jaw curvature and inter-implant distance impacted the accuracy of the IOS. Distortion and reduced reproducibility of T&P increased with the jaw curve from the anterior to the posterior regions and with greater distances between implants. The Trios3Shape IOS demonstrated the highest accuracy, while the 3Disc Heron IOS produced significant distortion in trueness.

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