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Evaluating the Accuracy of Intraoral Scanners Based on Implant Spacing: An In Vitro Study

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ABSTRACT

Introduction: Accurate impressions are essential for implant restorations. Intraoral scanners (IOS) have become well-established for capturing digital impressions. The aim of this study was to evaluate the trueness and precision of IOS in capturing implant positions in a partially edentulous maxilla.

Materials and Methods: Six implant analogs (DIO Implant. UF) in three maxillary acrylic models with Kennedy class 2 edentulousness (in canine, premolars, and molars area) were placed in three groups A: 10 mm inter-implant distance (IID), B: 20 mm IID and C: 30 mm IID. After fixing the scan bodies, 10 digital impressions were recorded for each model using IOS (TRIOS 3Shape). In addition, one scan per model was performed with the laboratory scanner (Smart Optic Activity 885), and STL (Standard Tessellation Language) files were collected. All files were analyzed using GeoMagic Control software. Accuracy was assessed by comparing IOS data with high-precision laboratory scanner data and the repeatability of IOS within groups.

Results: Inter-implant distance reduced IOS trueness between all three groups significantly ($p < 0.001$). The accuracy was greatest at the 10 mm inter-implant distance through IOS. Mean IOS precision was higher in the 10 mm group, but this difference was not significant ($p = 0.057$).

Conclusion: Despite in vivo limitations, the present study shows that larger inter-implant distances reduce IOS trueness and precision for spaced implant impressions, potentially affecting digital impression accuracy and prosthetic outcomes.

Keywords: Intraoral Photography, Dental Impression Techniques, Dental Implants, Surgical Dental Prosthesis

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Introduction

In the 1970s, Duret created digital impression systems for direct impressions. Optical scanners appeared in 1982, although early intraoral versions lacked accuracy [1, 2]. By 1985, Sirona's (North Carolina, USA) CEREC (Chairside Economical Restoration of Esthetic Ceramics) used infrared light for 3D imaging and milling, initially for inlays and later for veneers and bridges [3, 4].

The adoption of CAD/CAM technology in the early 2000s led to significant advancements in intraoral scanners, with 3M acquiring the Lava™ Chairside Oral Scanner in 2006 and Cadent launching iTero, enabling full-arch scans to labs by 2008. Companies such as Carestream and 3Shape facilitated adoption among dentists [3, 5-7]. Intraoral scanners have evolved for implant prostheses. Modern titanium implants are now widely accepted due to tech advancements [8-13]. Different materials are used in several implant impression techniques, such as direct splinted open-tray and indirect closed-tray techniques [14, 15].

Initially starting with healing abutments in 2004, intraoral scanners replaced traditional methods by using scan bodies for accurate, patient-friendly scanning. The CAD/CAM prostheses requires impression using these types of scanners to be of benefit due to increased accuracy, dissolving the gag reflex in many patients, reducing cost and convenience of a clinical setting where may be required functional impressions to improve a poorly defined denture at a secondary appointment, whilst conventional impressions will cause gagging and are prone to inaccuracy and defects which lead to complex denture iterations [16-19].

Intraoral scanners are now more cost-effective and precise than traditional laboratory scanners for digitizing casts [20]. Issues arise concerning scanning shiny or transparent surfaces, which can be addressed by minimizing saliva/encasing samples with titanium oxide powder [21]. According to studies, scanning paths play an important role in accuracy. The zigzag method (i.e., sequential S-shaped path) is often recommended [22]. Intraoral scanners differ in speed, powder requirement, and price, but reliability rests on trueness and precision [23-25].

Trueness means how closely a scan matches the actual dimensions of the object. To assess trueness, a high-accuracy reference scanner is needed to evaluate the deviation between the scanned model and the actual size of the scanned object [26-28]. Precision means the consistency of repeated scans of the same object, regardless of their closeness to the true value [29]. To assess precision, multiple scans of the same object under the same conditions using the same intraoral scanner are essential. Several intraoral scanners are under development, and a few are already in clinical application. As digital dentistry continues to advance, future innovations will likely enhance accuracy, efficiency, and patient comfort.

Materials & Methods

The current study was approved by the Ethics Committee of Babol University of Medical Sciences (ethical number: IR.MUBABOL.HRI.REC.1398.134).

For the present study, three identical acrylic maxillary arch models with Kennedy Class II partial edentulism (edentulous area includes canines, premolars, and molars on one side) were chosen. Two dental implant analogs embedded in various inter-implant distances were included in each model:

Model 1: Implant analogs placed in the estimated position of teeth #3 and #5 with a 10 mm inter-implant distance.

Model 2: Implant analogs exhibit the correlating positions of teeth #3 and #6 with a 20 mm inter-implant distance

Model 3: Implant analogs at the estimated position of teeth #3 and #7 and inter-implant distance of 30 mm.

The implant analogs were placed using a milling machine (AF 30; NOUVAG AG, Frauenfeld, Switzerland), ensuring parallel placement in the acrylic base. A digital caliper was used to confirm the accuracy of the inter-implant distances.

Each implant analog was retained in its designated position with self-curing acrylic resin (Duralay; Reliance Dental, Chicago, USA), thus preventing any displacement and ensuring stability throughout the study.

After securing the scan bodies, digital impressions were captured using the TRIOS scanner, following the manufacturer's zigzag scanning protocol (TRIOS, 3Shape, Copenhagen, Denmark) (Figure 1). The resulting scans were stored in STL (Standard Tessellation Language) format.

To determine the accuracy of the intraoral scanner, after fixing the scan bodies, all three acrylic models were scanned by a high-precision laboratory scanner (Smart Optic Activity 885, Bochum, Germany). The reference data consisted of STL files obtained from the laboratory scanner. The obtained STL files were analyzed by using the engineering software, Geomagic Control 2013 (3D Systems, Rock Hill, USA). The assessment process consisted of:

Each of the STL files from the intraoral scanner was superimposed on the matching reference STL files from the laboratory scanner. The Best-fit alignment algorithm was used to overlay the intraoral scans on top of the laboratory scan reference. To achieve this, the mean deviation of pixel coordinates between the two scans was calculated to evaluate the trueness of the intraoral scanner.

The 10 intraoral scans of each model were overlapped with one another through the Best-Fit algorithm. The repeatability (precision) of the intraoral scanner was assessed by measuring the mean deviation of pixel coordinates among repeated scans (Figure 1). At first, for assessing the normality of data distribution, we used the Shapiro-Wilk Test. Therefore, the trueness and precision of IOS were evaluated by the two-way ANOVA test. All of the statistical analyses were done with SPSS 26 (SPSS Inc., Chicago, IL, U.S.A.).

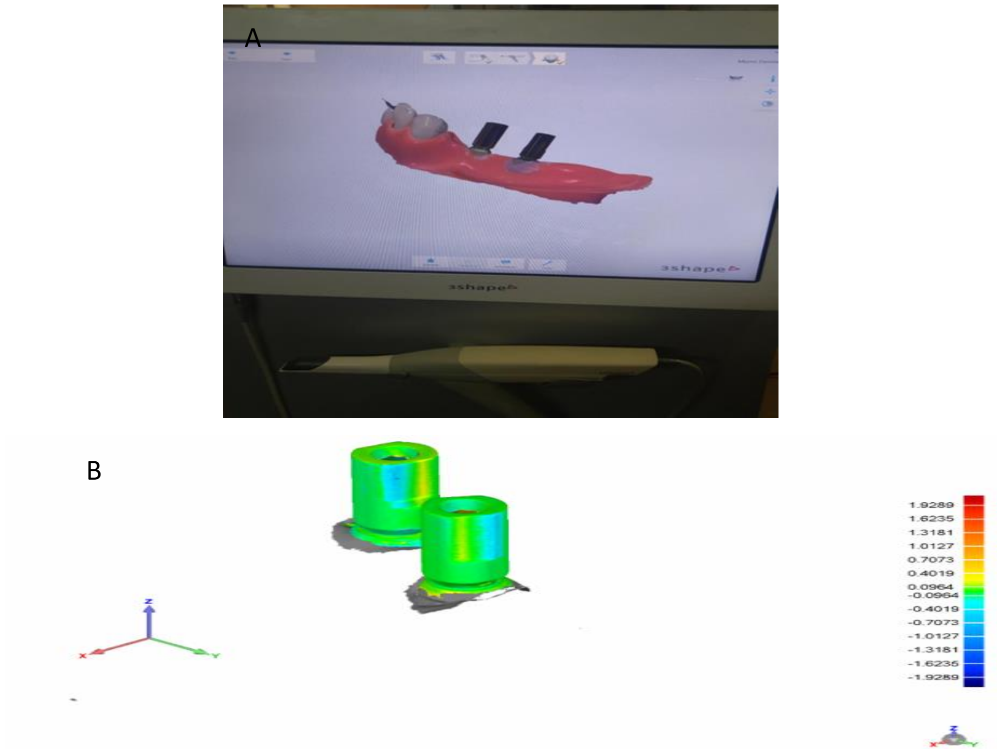

Figure 1 – A: An example of a scan produced by an intraoral scanner, B: Investigating the accuracy and repeatability of the intraoral scanner by comparing the trimmed body scans of the test model and the reference model using Geomagic software and the Best-Fit algorithm.

Results

In this in vitro study, 30 samples were divided into three groups of 10 and evaluated in two aspects: scanner accuracy and repeatability.

Scanner Accuracy

The normality of data distribution was confirmed using the Shapiro-Wilk test (Table 1). Box plot analysis demonstrated that the deviation range at 20 mm and 30 mm was notably greater than at 10 mm. Additionally, the mean deviation initially increased from 10 mm to 20 mm and then decreased at a 30 mm distance.

Analysis of variance (ANOVA) indicated a statistically significant effect of implant distance on scanner accuracy ($p < 0.001$). The results showed that accuracy was highest at 10 mm, lowest at 20 mm, and intermediate at 30 mm, with significant differences between all three groups (Table 1).

Table 1 - Descriptive statistics of scanner accuracy and repeatability based on implant distance and the results of the Shapiro-Wilk test for normality of data distribution.

Distance (mm)	10 mm	20 mm	30 mm
Scanner Accuracy			
Sample Size	**10**	**10**	**10**
Degrees of Freedom	**10**	**10**	**10**

Median	**0.0915**	**0.1906**	**0.1356**
Mode	**0.0922**	**0.1777**	**0.1380**
Standard Deviation	**0.02513**	**0.03407**	**0.04413**
Minimum	**0.06**	**0.16**	**0.06**
Maximum	**0.13**	**0.27**	**0.20**
Test Statistic	**0.939**	**0.884**	**0.964**
p-value	**0.544**	**0.147**	**0.831**
Test Result	**Normal**	**Normal**	**Normal**
Scanner Repeatability			
Sample Size	**10**	**10**	**10**
Degrees of Freedom	**10**	**10**	**10**
Median	**0.057660**	**0.100820**	**0.108830**
Mode	**0.061300**	**0.094800**	**0.092850**
Standard Deviation	**0.0287563**	**0.0420181**	**0.0671626**
Minimum	**0.0223**	**0.0402**	**0.0482**
Maximum	**0.0892**	**0.2021**	**0.2736**
Test Statistic	**0.846**	**0.855**	**0.811**
p-value	**0.052**	**0.066**	**0.051**
Test Result	**Normal**	**Normal**	**Normal**

The data distribution normality statistical test was the Shapiro-Wilk test.

Table 2 - Mean ± SD of mismatch in study groups.

Distance (mm)	Compared with Group	Mean Difference (I-J) ± Std. Error	P value	Lower Bound	Upper Bound
Scanner Accuracy					
10	**2**	**-0.099 ± 0.014**	**0.000**	**-0.130**	**-0.068**
10	**3**	**-0.044 ± 0.015**	**0.018**	**-0.079**	**-0.009**
20	**1**	**0.099 ± 0.014**	**0.000**	**0.068**	**0.130**
20	**3**	**0.055 ± 0.017**	**0.011**	**0.016**	**0.094**

30	**1**	**0.044 ± 0.015**	**0.018**	**0.009**	**0.079**
30	**2**	**-0.055 ± 0.017**	**0.011**	**-0.094**	**-0.016**
Result of ANOVA Test		**F = 20.59, p < 0.001**			
Scanner Repeatability					
10	**2**	**-0.043 ± 0.020**	**0.059**	**-0.088**	**-0.002**
10	**3**	**-0.051 ± 0.027**	**0.092**	**-0.113**	**-0.010**
20	**1**	**0.043 ± 0.020**	**0.059**	**-0.002**	**0.088**
20	**3**	**-0.008 ± 0.015**	**0.597**	**-0.041**	**0.025**
30	**1**	**0.051 ± 0.027**	**0.092**	**-0.010**	**0.113**
30	**2**	**0.008 ± 0.015**	**0.597**	**-0.025**	**0.041**
Result of ANOVA Test		**F = 3.37, p = 0.057**			

The statistical test was the two-way ANOVA test.

Scanner Repeatability

The Shapiro-Wilk test confirmed the normal distribution of data (Table 1). Box plot analysis showed greater deviation at 20 mm and 30 mm than at 10 mm.

ANOVA results demonstrated a borderline significant effect of implant distance on scanner repeatability ($p = 0.057$). The repeatability decreased as the implant distance increased. A marginally significant difference was observed between the 10 mm group and the 20 mm and 30 mm groups, while no significant difference was found between the 20 mm and 30 mm groups ($p = 0.597$) (Table 2).

Discussion

Our findings confirm that increasing inter-implant distance reduces intraoral scanner accuracy and repeatability. Specifically, accuracy declined from 10 mm to 20 mm but improved from 20 mm to 30 mm, with the highest accuracy at 10 mm and the lowest at 20 mm. While the accuracy difference between the 20 mm and 30 mm was statistically significant, it may reflect potential laboratory error. Also, scanning algorithms may struggle at 20mm but perform better at 30mm due to feature variations. The primary conclusion regarding accuracy was drawn by comparing the 10 mm distance with the 20 mm and 30 mm distances.

Numerous researchers have studied implant impression errors that increase costs for patients and clinicians. With the rise of intraoral scanners in dentistry, studies have evaluated their accuracy and repeatability. A comprehensive review by Alkadi highlighted factors affecting scanning accuracy, including scanner type, operator skill, calibration, oral anatomy, ambient conditions, and scanning aids [9]. The present study used a TRIOS [9, 30, 31].

Nedeclu et al. found intraoral scanners had better repeatability than conventional impressions, with comparable accuracy, while the accuracy of conventional impressions was comparable to that of the CEREC and Trios scanners and higher than the CEREC Omnicam [32]. Winkler et al. noted no significant accuracy difference between CS 3600 and Trios 3Shape scanners, but Trios showed better repeatability [33]. Also, Zarone et al. found intraoral scanning (TRIOS 3 Pod) for a completely edentulous maxilla to be more accurate and consistent than laboratory scanning (DScan 3) in an in-vitro study [34]. Similarly, Kulchotirat et al. examined inter-implant distances using TRIOS3 and CEREC Omnicam scanners, finding increased trueness and precision errors with greater distances. Angle deviation peaked at 14 mm but was not clinically significant. They concluded that inter-implant distance impacts scanner accuracy, with potential clinically significant deviations in partially edentulous arches [35].

Our findings align with Flügge et al., who observed decreased intraoral scanner repeatability (Trios, iTero, True Definition) as inter-implant distance increased in gypsum models with metallic scan bodies [36]. Similarly, Hironary et al. found digital impressions more accurate for partially edentulous mandibular models, with larger scanner heads enhancing accuracy and repeatability, though conventional impressions showed superior repeatability [30]. This suggests that inter-implant distance variations may affect intraoral scanner data accuracy. Amornvit et al. studied 10 intraoral scanners accuracy (2015-2020) using a maxillary dental model. Each scanner was tested five times for trueness and precision. Precision was consistent, but trueness varied, with accuracy decreasing over longer distances. The Trios series performed best [28].

Imburgia et al. assessed four intraoral scanners (True Definition, Omnicam, Trios, Carestream CS3600) on gypsum models with three and six implant analogs. All, except Trios, were more accurate in partially edentulous models [31]. Despite greater inter-implant distances in fully edentulous models, their findings differ from ours, with Trios showing no significant accuracy difference. Various scan body materials, such as metal, titanium, and polyether ether ketone (PEEK), are used with intraoral scanners [37]. Our study used metallic scan bodies. Mizumoto et al. found that scan body material significantly impacts scanner accuracy and noted superior accuracy with Zimmer Biomet PEEK scan bodies [38]. Thus, had different scan body materials been used in our study, variations in reported errors might have occurred.

Conclusion

Considering the limitations of this laboratory study, we conclude that the mean accuracy is lower for spaced implants in impression-taking, and as the distance increases between implants, the repeatability of the impression linearly diminishes. A limitation of this study is the use of intraoral scanners on models rather than clinical patients. Future studies should explore in vivo applications. One of the strengths of this study is the implant placement on a maxilla model, as opposed to a flat metal plate, making this study more clinically relevant.

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Conflict of Interest

There is no conflict of interest to declare.

Author’s Contribution

Sina Sabzevari developed the original idea and protocol, and summarized the study. Hemmat Gholinia analyzed results and developed final conclusion. Afsane Mokhtari drafted the manuscript and edited the article. The study was supervised and edited by Maryam Rezaei Dastjerdi, Saeed Sabzevari, and Hamidreza Rajati Haghi.

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