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Effects of Operator Experience and Scanning Distance on Intraoral Scanner Accuracy

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ABSTRACT

Aim: This study aimed to evaluate the effect of operator experience and scanning distance on the accuracy of the intraoral scanner in terms of trueness and precision.

Material and Methods: Reference data were obtained by scanning a partially edentulous gypsum model with implant analogs in regions 15, 16, 26, and 27 using a desktop scanner. Two expert dentists, one experienced and one inexperienced, performed test scans using the Trios 5 scanner. All data were transferred to analysis software. The scan bodies in the test scans were superimposed with the reference scan bodies for trueness measurement using a best-fit algorithm, calculating the deviation between the datasets. Precision measurement involves aligning the test scan data with each other using the same method. The effect of operator experience and scanning distance on scanner accuracy was evaluated using independent-sample t-tests.

Results: Full-arch scans exhibited higher trueness and precision deviations than partial-arch scans. For partial-arch scans by the experienced operator, the mean trueness deviation was 7.45µm, compared to 55.56µm for full-arch scans ($p<0.001$). Inexperienced operator results were 7.60µm and 58.90µm, respectively ($p<0.001$). Operator experience had no significant effect on trueness. For partial-arch scans performed by the experienced operator, the mean precision deviation was 2.73µm, compared to 33.87µm for full-arch scans ($p<0.001$). Inexperienced operator results were 3.36µm and 39.79µm, respectively ($p<0.001$). Operator experience significantly affected precision in partial-arch scans ($p=0.044$) but not in full-arch scans ($p=0.563$).

Conclusion: Scanner accuracy decreased with increasing scanning distance. The effect of operator experience on scanner accuracy was insignificant.

Operatör Tecrübesi ve Tarama Mesafesinin Ağız İçi Tarayıcı Hassasiyetine Etkisi

Makale Bilgisi

Makale Geçmişi

Geliş Tarihi: 25.06.2024
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Anahtar Kelimeler:
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Tecrübe,
Hassasiyet,
Doğruluk,
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ÖZET

Amaç: Bu çalışmanın amacı, operatör tecrübesinin ve tarama mesafesinin ağız içi tarayıcı hassasiyetine etkisini doğruluk ve kesinlik açısından değerlendirmektir.

Gereç ve Yöntemler: 15, 16, 26 ve 27 numaralı bölgelerinde implant analoğu bulunan kısmi dişsiz alçı modelin masaüstü tarayıcı ile taranmasıyla referans veriler elde edildi. Test taramaları, ağız içi tarayıcı kullanma deneyimi olan ve olmayan iki uzman diş hekimi tarafından Trios 5 tarayıcı kullanılarak gerçekleştirildi. Bütün veriler analiz yazılımına aktarıldı. Doğruluk ölçümü için test taramalarındaki tarama gövdeleri referans tarama gövdeleriyle "best-fit" algoritması kullanılarak çakıştırıldı ve iki veri seti arasındaki sapma hesaplandı. Kesinlik ölçümü, aynı prosedür kullanılarak test tarama verilerinin birbiri ile çakıştırılması ile gerçekleştirildi. Operatör tecrübesi ve tarama mesafesinin tarayıcı hassasiyetine etkisi bağımsız-örnekler t-testi ile değerlendirildi.

Bulgular: Tam ark taramalar kısmi ark taramalardan daha fazla doğruluk ve kesinlik sapması gösterdi. Tecrübeli operatör tarafından gerçekleştirilen kısmi ark taramalarında ortalama doğruluk sapması 7,45µm iken tam ark taramalarında 55,56µm bulundu ($p<0,001$). Tecrübesiz operatör taramalarında bu değerler sırası ile 7,60µm ve 58,90µm idi ($p<0,001$). Operatör tecrübesinin doğruluk sapması üzerine etkisi anlamlı değildi. Tecrübeli operatör tarafından gerçekleştirilen kısmi ark taramalarında ortalama kesinlik sapması 2,73µm iken tam ark taramalarında 33,87µm bulundu ($p<0,001$). Tecrübesiz operatör taramalarında bu değerler sırası ile 3,36µm ve 39,79µm idi ($p<0,001$). Operatör tecrübesi, kısmi ark taramalarında hassasiyeti önemli ölçüde etkiledi ($p=0,044$), ancak tam ark taramalarında etkilemedi ($p=0,563$).

Sonuç: Tarama mesafesi arttıkça tarayıcı hassasiyeti azaldı. Operatör tecrübesinin tarayıcı hassasiyete etkisi anlamlı değildi.

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INTRODUCTION

Intraoral scanners have become an essential part of digital technologies in dentistry. These devices offer numerous advantages such as faster and more comfortable impressions than traditional methods, real-time scanning and visualization, virtual image management, convenient archiving, and quick and effective communication with patients and technicians.[1,2] However, the accuracy of intraoral scanners can be influenced by a variety of factors such as scanning distance and operator experience.[3–6] High precision impressions are required for the passive fit and long-term success of prostheses. Therefore, it is crucial to understand the factors affecting impression accuracy and minimize their effects.

According to ISO 5725-1, accuracy encompasses both trueness and precision. Trueness refers to how close the measurement is to the actual dimensions of the object, while precision relates to the consistency of the device when scanning the same object multiple times.[7] In situations with limited scanning distance, intraoral scanners typically provide accuracy that meets clinical standards.[8–10] However, as the scanning distance increases, the accuracy of intraoral scanners becomes questionable. Current studies seem to agree that the accuracy of scanners decreases with increasing scanning distance.[9–18] This is attributed to stitching errors while creating three-dimensional images. Intraoral scanners create 3D images step by step by overlaying the images obtained during scanning. Stitching errors can occur during the merging of two images, and as the scanning distance increases, these errors accumulate, resulting in more significant overall errors.[4,9] Additionally, the lack of landmarks in edentulous areas and the similarity in the shapes of implant scan bodies pose greater challenges during image merging.[18,19] Furthermore, the learning curve and operator experience are also reported to be factors that can affect the accuracy of digital scanning.[12,13,16,20–22] However, some studies have reported that operator experience does not affect the accuracy of intraoral scanners.[15,23]

With advancements in dentistry, the use of digital technologies is increasing daily. In parallel, intraoral scanner technology is rapidly developing and evolving. These developments require studies testing the accuracy of different intraoral scanners for different clinical scenarios. This in vitro study aims to evaluate the effect of operator experience and scanning distance on the accuracy of intraoral scanners. The null hypotheses of the study were that the accuracy of intraoral scanners will not be affected by (1) operator experience and (2) scanning distance.

MATERIAL AND METHODS

Study Design

In this study, the effect of operator experience (experienced and inexperienced) on the accuracy of intraoral scanners was evaluated at two different scanning distances (half arch and full arch). A partial edentulous plaster model with four implant analogs (Implant Analogue, Institut Straumann AG, Basel, Switzerland) in the regions of teeth numbered 15, 16, 26, and 27 was used as the master model (Figure 1). Scan bodies (CARES Mono scanbody, Straumann) were screwed onto the implant analogs in the master model. To obtain reference scan data, the master model was scanned with a desktop scanner with an accuracy of 0.4 μm (Vinyl High Resolution, Smartoptics, Oslo, Norway). Two specialist dentists performed test scans, one with and one without intraoral scanner experience, using the Trios 5 version 22.1.6 (3Shape, Copenhagen, Denmark)

intraoral scanner. Each segment in the test scans (partial arch and full arch) was compared with the corresponding reference scan (trueness assessment) and among themselves (precision assessment).

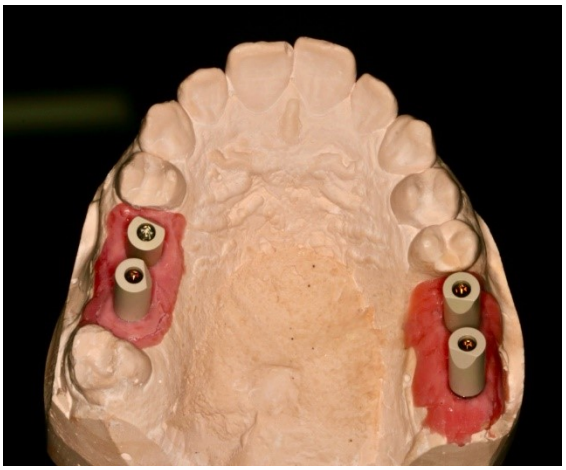

Figure 1: Master model

Obtaining Digital Impressions with Intraoral Scanners

Before the test scans of each group, the intraoral scanner was calibrated. Test scans were performed by an operator (T.S) with more than five years of experience with intraoral scanners and an operator (A.B.S) without prior experience using intraoral scanners. Each operator performed five scans before the test scans to avoid training bias.[16] Then, each operator conducted 12 scans for the test scans. A new case was created for each test scan by selecting implant and tooth information on the case creation page. Scans were performed in intraoral scanning mode. The AI Scanning feature was activated, which intelligently separates teeth and surrounding gums from unwanted surfaces like the tongue, fingers, and mouth mirror and automatically removes them from the scan. All scans started from the left posterior scan body and proceeded continuously until reaching the opposite end. The occlusal-palatal-buccal scanning technique recommended by the manufacturer was used for scanning in tooth regions, while the zigzag technique described in previous studies was used for implant regions.[24] A standard 5-minute waiting period was applied between two scans to prevent fatigue-related errors and allow the scanner to cool down.

Calculation of Trueness and Precision Deviations

All scan data were transferred to a computer-aided design program (Exocad dental DB 3.1, Align Technology, Darmstadt, Germany) in standard tessellation language (STL) format. The scan bodies in the scan data were superimposed with the original scan bodies in the digital library. The superimposed original scan bodies were exported in two segments to evaluate the effect of scanning distance on accuracy. For the partial arch, the scan bodies of numbers 26 and 27 were selected and exported, while for the full arch, the scan bodies of numbers 15, 16, 26, and 27 were selected and exported. As stated in previous studies, this method allowed for removing irrelevant parts of the model and acquiring original scan bodies with flawless surfaces for analysis.[8,16] These data were then transferred to three-dimensional (3D) analysis software (CloudCompare version 2.13, CloudCompare.org). For the trueness deviation measurement, the scan bodies of each segment in the test scans (partial arch or full arch) were superimposed with the corresponding reference scan bodies using a "best-fit" alignment algorithm. This algorithm calculated the 3D deviation between the superimposed data sets as the root mean square (RMS) error.[14,15,21] Additionally, the software generated a color mapping of the 3D deviation for each measurement (Figure 2). The precision deviation measurement was performed using the same procedure. Unlike trueness deviation, the test scan data within each group were superimposed with each other, not with the reference scan data, to calculate the 3D deviations.[8,9,16] Thus, 12 measurements were

performed for each group in the trueness assessment, while 66 measurements were performed for each group in the precision assessment.

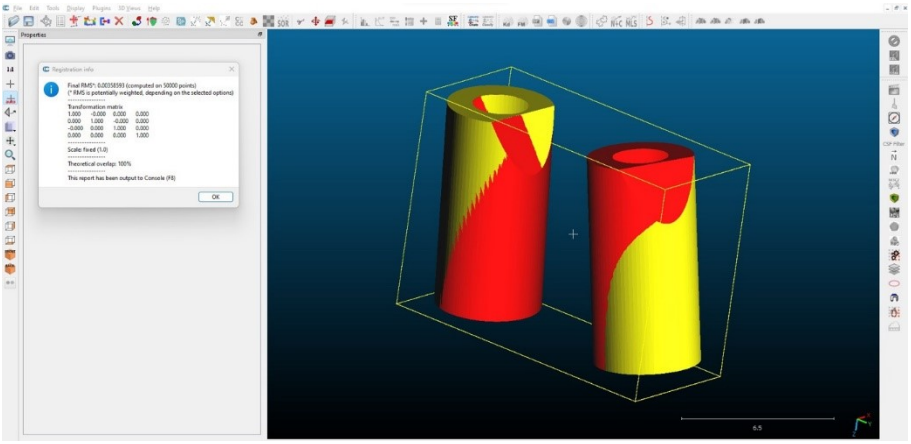

Figure 2A: Colorimetric map of superimposed scan bodies of partial arch scans and calculation of 3D deviation between the two data sets.

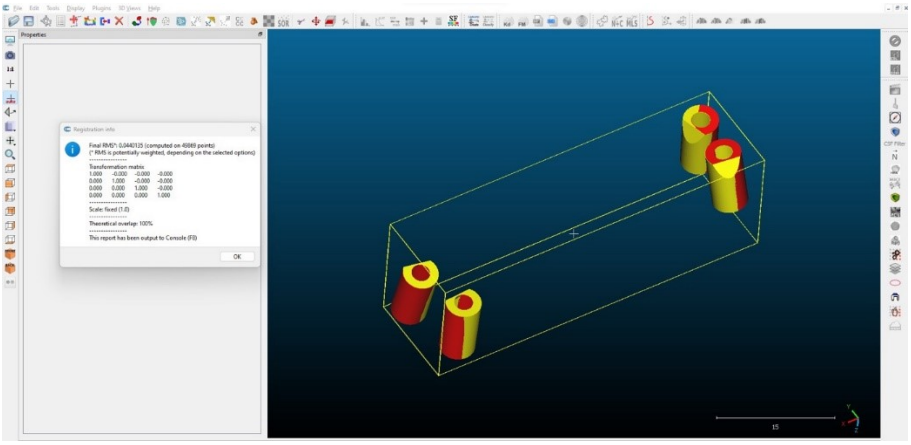

Figure 2B: Colorimetric map of superimposed scan bodies of full arch scans and calculation of 3D deviation between two data sets.

Outcomes and Power Analysis

The outcomes of this study were trueness and precision deviations. The sample size was determined considering both outcomes. When considering the effect of scanning distance on scanner accuracy, power analysis results with effect sizes of d=0.842 (precision) and d=1.908 (trueness), a=0.05, and power=0.90 indicated that a total of 17 scans for precision and a total of 6 scans for trueness are required.[16] When considering the effect of operator experience on scanner accuracy, power analysis results with effect sizes of d=1.218 (precision) and d=0.740 (trueness), a=0.05, and power=0.90 indicated that a total of 10 scans for precision and a total of 22 scans for trueness are required.[16] Therefore, 12 scans per group were deemed appropriate based on the G-power calculation results.

Statistical Analysis

Data were analyzed using SPSS software version 22.0 (IBM Corp.). The normality of the data was assessed using the Shapiro-Wilk test. To examine statistically significant differences in operator experience and scanning distance, an independent-sample t-test was used if the data were normally distributed, and the Mann-Whitney U test was used if the data were not normally distributed. The significance level was determined as $p<0.05$.

RESULTS

Full arc scans performed by both experienced and inexperienced operators showed statistically higher trueness deviation and precision deviation compared to partial arc scans (Figures 3 and Figure 4). Table 1 presents the mean and standard deviation values for trueness assessment, as well as the results of independent samples t-tests for experience comparison and scan distance comparison. In partial arc scans performed by experienced operators, the mean trueness deviation was 7.45 ± 0.60 µm, while in full arc scans, it was 55.56 ± 16.56 µm ($p<0.001$). For inexperienced operators, these values were 7.60 ± 1.36 µm and 58.90 ± 18.51 µm, respectively ($p<0.001$). Operator experience did not significantly affect trueness deviation in partial and full arc scans (Table 1).

Table 1: 3D trueness deviations in partial and full arch scans (µm)

	Inexperienced	Experienced	Test Statistics*	P
Partial arch	7.60 ± 1.36	7.45 ± 0.60	0.342	0.737
Full arch	58.90 ± 18.51	55.56 ± 16.56	0.465	0.646
Test Statistics*	-9.577	-10.061		
P	**<0.001**	**<0.001**		

*Independent samples t-test; Mean ± standard deviation.

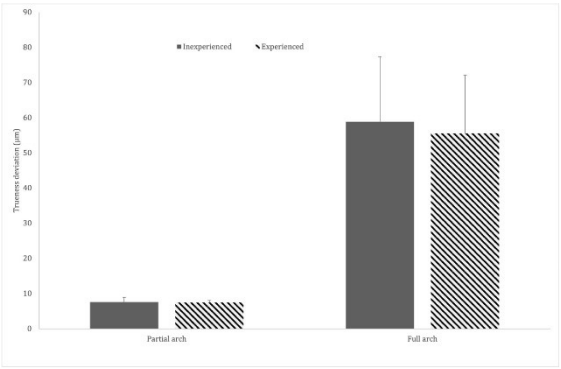

Figure 3: Trueness deviations in partial and full arch scans performed by experienced and inexperienced operators.

Table 2 presents the median and minimum-maximum values for precision assessment, along with the results of Mann-Whitney U tests for experience comparison and scan distance comparison. In partial arc scans performed by experienced operators, the mean precision deviation was 2.97 ± 1.10 µm, while in full arc scans, it was 39.03 ± 22.44 µm ($p<0.001$). For inexperienced operators, these values were 3.33 ± 1.11 µm and 40.51 ± 21.60 µm, respectively ($p<0.001$). Operator experience had a significant effect on precision deviation in partial arc scans ($p=0.044$) but not in full arc scans ($p=0.563$) (Table 2).

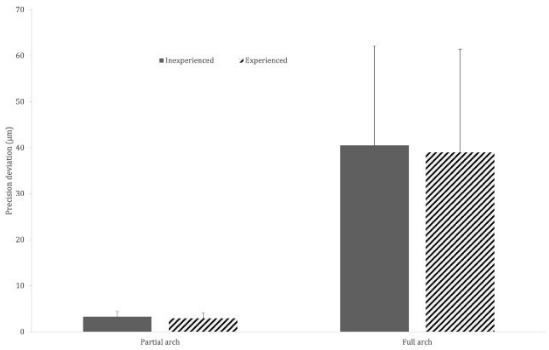

Figure 4: Precision deviations in partial and full arch scans performed by experienced and inexperienced operators.

Table 2: 3D precision deviations in partial and full arch scans (µm)

	Inexperienced	Experienced	Test Statistics*	P
Partial arch	3.36 (0.98 – 5.87)	2.73 (0.99 – 5.5)	1735.50	0.044
Full arch	39.79 (11.25 – 99.68)	33.87 (10.25 – 90.66)	2051.00	0.563
Test Statistics*	4356.00	4356.00		
P	<0.001	<0.001		

*Mann-Whitney U test; Median (min-max)

DISCUSSION

This study evaluated the effects of operator experience and scanning distance on the accuracy of the intraoral scanner in terms of trueness and precision. The key findings revealed that operator experience had a statistically significant effect on the precision of the intraoral scanners in partial arc scans but not in full arc scans. Additionally, operator experience did not have a statistically significant impact on the trueness of the intraoral scanner. These results have crucial implications for dental professionals, as they partially reject the first null hypothesis and entirely reject the second null hypothesis, indicating a significant difference in both the trueness and precision of the intraoral scanners between partial arc scans and full arc scans.

Previous studies have revealed that many factors can affect the accuracy of intraoral scanners. These factors can be described as the type of intraoral scanner, lighting conditions, scanning patterns, modification techniques, scan body systems, implant positions, the distance between implants, the number of implants, scanning distance, and operator experience.[8–18,20–22,24–29] The technology of intraoral scanners is rapidly evolving to minimize the impact of these factors and to obtain highly accurate digital impressions. In parallel with these developments, it is clinically significant to investigate the scanning accuracy of newly developed systems and present updated results. In this study, one of the most recent versions of intraoral scanner systems, the Trios 5, was used. When evaluating the results of studies investigating the accuracy of intraoral scanners, the reference scanner used should also be considered. In studies, a coordinate measuring machine, an industrial scanner, or a desktop scanner can be used as a reference scanner.[9–11,16–18,24] This study used a high-accuracy desktop scanner as the reference scanner, similar to other studies.[9,11,16,24]

The findings of this study showed that full arc scans performed by both experienced and inexperienced operators had statistically higher trueness deviation and precision deviations than partial arc scans. These results support previous studies on different clinical scenarios using various intraoral scanners, indicating that the scanner's accuracy decreases as the scanning distance increases, regardless of the scanner or clinical scenario type.[9–18] The results of this study revealed that trueness and precision deviations in full arc scans were approximately 8 to 13 times higher than those in partial arc scans. Therefore, in cases where the bilateral posterior region will be restored with an implant or tooth-supported restoration, as in this study, performing separate digital scans of the right and left sides without crossing the midline and saving them as individual files may enable the creation of restorations with higher accuracy.

Intraoral scanners are devices used in clinical workflows by dentists, dental hygienists, and dental students, and are gaining more prominence in clinical practice over time.[12,13,15,16,20–23] In this context, investigating the effect of operator experience on the accuracy of intraoral scanners is important both for predicting clinical outcomes and providing insights to professionals using these devices for the first time. Previous studies have reported varying results on the impact of experience on the accuracy of intraoral scanners. Some studies indicate that experienced operators achieve more accurate digital impressions than inexperienced operators, while others find no significant difference between experienced and inexperienced operator groups.[13,15,16,20–23]

This study found that operator experience did not significantly affect trueness deviation in partial and full arch scans. Additionally, the precision deviation was the same between experienced and inexperienced operators in full arch scans. In partial arch scans, the scans performed by experienced operators showed

statistically less precision deviation. However, since this difference was less than 1 μm, it was not clinically significant. Andriessen et all., a clinically acceptable distance deviation between two implants is reported to be 100 μm, a threshold widely accepted in many studies.[11,19,22] The trueness and precision deviations in scans performed by both experienced and inexperienced operators in this study were below the reported acceptable limit. These results indicate that even inexperienced operators, after a short learning curve, can obtain accurate digital measurements using intraoral scanners. It should be noted that the learning curve is individual-dependent, and the operator without intraoral scanner experience in this study was a highly clinically experienced specialist dentist.

The main limitation of this study is that it was conducted under in vitro conditions. Digital impressions made under in vivo conditions can be affected by numerous factors, including saliva, patient movements, and the unique characteristics of oral tissues. Because our study was conducted under controlled conditions without these variables, the results may not fully represent actual clinical conditions. Another study limitation is the assessment of intraoral scanner accuracy for limited clinical scenarios. More in vitro and in vivo studies will be needed to understand better how intraoral scanners perform in different situations. This emphasizes the importance of ongoing research to improve the accuracy and reliability of intraoral scanners continually.

CONCLUSION

Within the limitations of this study, the following conclusions were reached:

1. Full arch scans showed significantly higher trueness and precision deviations than partial arch scans.
2. No significant difference was found between scans performed by experienced and inexperienced operators.

Ethical Approval

This in-vitro study does not require ethics committee approval.

Financial Support

The authors declare that this study received no financial support.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

Author Contributions

Design: MG, NG, Data collection: MG, NG, Analysis and interpretation: NG, CA, Literature review: MG, CA, Writing: MG, NG.

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