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Research / Araştırma Makalesi

Accuracy of An Intraoral Scanner That Uses Optical Triangulation and Confocal Microscopy Technology For Full-Arch Digital Implant Impression: *in Vivo* and *in Vitro* Evaluation

Tam Ark Dijital İmplant Ölçüsü için Optik Üçgenleştirme ve Konfokal Mikroskopi Teknolojisini Kullanan İntraoral Tarayıcının Hassasiyeti: *in Vivo* ve *in Vitro* Değerlendirme

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ABSTRACT

Background: The purpose of this study was to analyse the accuracy of the full-arch digital implant impressions under both in vivo and in vitro conditions.

Methods: A provisional prosthesis was fabricated for a patient with four implants placed in the edentulous maxilla. The master model was obtained using provisional prostheses. Both intraoral scans (IOS group) and extraoral scans (EIOS group) of the master model were performed using an intraoral scanner. The accuracy of the IOS and EIOS groups was calculated for three distances and three angles between the scan bodies (A-B, A-C, and A-D), as well as for the mean deviations of all segments (total deviations).

Results: Trueness and precision showed a tendency to decrease as the scanning range increased in both groups. The mean total distance trueness was found to be 121.53±89.55 µm and 57.75±65.17 µm for the IOS group and the EIOS group, respectively (p=.001). The mean total angle trueness was found to be 0.53±0.28 degrees and 0.13±0.09 degrees for the IOS group and the EIOS group, respectively (p<.001). The mean total distance precision was found to be 76.73±87.26 µm and 59.57±70.44 µm for the IOS group and the EIOS group, respectively (p=.051). The mean total angle precision was found to be 0.32±0.24 degrees and 0.13±0.09 degrees for the IOS group and the EIOS group, respectively (p<.001).

Conclusion: The accuracy of in vivo full-arch digital implant impressions was lower than in vitro and fell below the previously reported acceptable threshold.

Keywords: Dental arches, Dental impression technique, Digital technology, Dimensional measurement accuracy.

ÖZ

Amaç: Bu çalışmanın amacı, tam ark dijital implant ölçülerinin hassasiyetini hem *in vivo* hem de *in vitro* koşullar altında analiz etmektir.

Gereç ve Yöntemler: Tam dişsiz üst çenesine dört implant yerleştirilen hastaya bir geçici protez yapıldı. Geçici protezler kullanılarak ana model elde edildi. Ağız içi tarayıcı kullanılarak intraoral taramalar (IOS grubu) ve ana modelin ekstraoral taramaları (EIOS grubu) gerçekleştirildi. IOS ve EIOS gruplarının hassasiyeti, tarama gövdeleri (A-B, A-C ve A-D) arasındaki üç mesafe ve üç açının yanı sıra tüm segmentlerin ortalama sapmaları (toplam sapmalar) için hesaplandı.

Bulgular: Her iki grupta da tarama aralığı arttıkça doğruluk ve kesinlik azalma eğilimi gösterdi. Ortalama toplam mesafe doğruluğu IOS grubu ve EIOS grubu için sırasıyla 121.53±89.55 µm ve 57.75±65.17 µm olarak bulundu (p=0.001). Ortalama toplam açı doğruluğu IOS grubu ve EIOS grubu için sırasıyla 0.53±0.28 derece ve 0.13±0.09 derece olarak bulundu (p<.001). Ortalama toplam mesafe kesinliği IOS grubu ve EIOS grubu için sırasıyla 76.73±87.26 µm ve 59.57±70.44 µm olarak bulundu (p=0.051). Ortalama toplam açı kesinliği IOS grubu ve EIOS grubu için sırasıyla 0.32±0.24 derece ve 0.13±0.09 derece olarak bulundu (p<.001).

Sonuç: *İn vivo* tam ark dijital implant ölçülerinin hassasiyeti *in vitroya* göre daha düşüktü ve daha önce bildirilen kabul edilebilir eşiğin altına düştü.

Anahtar Kelimeler: Dental ark, Dental ölçü tekniği, Dijital teknoloji, Boyutsal ölçüm doğruluğu.

INTRODUCTION

The digital impressions made through intraoral scanners have many advantages. Digital impressions are more comfortable and require less time than traditional impressions. Intraoral scanners have real-time scanning and visualization, virtual image management, and convenient archiving. They provide fast and effective communication with patients and technicians.[1] Additionally, since there is no need for impression material or plaster, the dimensional distortion problem is eliminated, and the aseptic chain can be better controlled.[2] Although intraoral scanners have been used successfully for partial-arch digital implant impressions, they are not accurate enough for clinical application in full-arch digital implant impressions.[2-6] However, testing the accuracy of intraoral scanners under *in vivo* conditions, where the digital impression is obtained directly from the patient's mouth, is challenging due to the difficulty in obtaining reference data.

Accuracy of the impression directly affects the success of the restorations. Accuracy is defined in terms of trueness and precision (ISO5725-1).[7] The trueness refers to how close the impression is to the actual dimensions of the object, while precision is defined as the consistency of the device in repeated scans of the object. Previous *in vitro* studies, in which digital impressions were obtained extraorally from an artificial jaw model, reported that the accuracy of intraoral digital impressions was equal to or superior to conventional impressions.[8-11] The accuracy of intraoral scanners varies depending on scan range, scan pattern, scanner type, scan body type, and operator experience.[5,6,8,12-24] However, the accuracy of digital impressions can be influenced by intraoral conditions.[25,26] Limited research has been conducted on the *in vivo* accuracy of intraoral scanners for full-arch digital implant impressions.[25,27-29] Rutkunas et al.[25] reported a mean distance deviation of 23.6 µm for Trios 3 (3Shape, Copenhagen, Denmark). Chochlidakis et al.[28] and Mandelli et al.[27] reported a mean 3D deviation of 162 µm and 483 µm for True Definition (3M Espe, St. Paul, Minnesota), respectively. Nevertheless, to the best of our knowledge, there is no study in the literature assessing the *in vivo* accuracy of the CEREC Omnicam (Dentsply Sirona, Bensheim, Germany) scanner using optical triangulation and confocal microscopy technologies for full-arch digital implant impressions.

The objective of this study was to analyse the trueness and precision of the CEREC Omnicam for full-arch digital implant impressions under both *in vivo* (intraorally) and *in vitro* (on the master model) conditions. The null hypotheses were that (1) there would be no difference in the

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trueness between *in vivo* and *in vitro* acquisitions, and (2) there would be no difference in the precision between *in vivo* and *in vitro* acquisitions.

MATERIAL AND METHODS

The Erciyes University Clinical Research Ethics Committee reviewed and approved the procedures of this study (Approval number: 2023/557). All procedures were conducted following the principles of the Helsinki Declaration revised in 2013. A participant who had 4 implants (Straumann BLX, Institut Straumann AG, Switzerland) placed in the edentulous maxilla was included in the study after providing signed informed consent.

A provisional all-acrylic denture was fabricated for the immediate loading of four implants, supporting the maxillary cross-arch fixed prosthesis. Following the implant surgery, multiunit abutments (Straumann Screw Retained Abutment) were connected to the implants. Titanium cylinders (Straumann Temporary Abutment) were screwed onto the abutments, and access holes were drilled on the prosthesis to accommodate the titanium cylinders. After adjusting the position of the prosthesis in the mouth, it was fixed to the titanium cylinders using light-cured pattern resin (Jig Box Pattern Resin; Seoul, Korea). The prosthesis with the titanium cylinders was then removed from the mouth. The palatal portion of the prosthesis and the excess part of the titanium cylinders were trimmed. The inner part of the prosthesis was modified by adding acrylic resin to create a convex shape. After polishing and finishing, a provisional prosthesis with titanium copings was delivered to the patient. Following a 3-month period for osteointegration, the provisional prosthesis was removed. Laboratory analogues were attached to the titanium cylinders of the provisional prosthesis. Gingiva modelling silicone (Gingifast Elastic; Zhermack, Badia Polesine, Italy) was injected into the inner surface of the prosthesis for soft tissue modelling, and a master model was poured with the type IV stone (Elite Rock Fast; Zhermack). Thus, similar to previous studies, the implant positions in the mouth were transferred to the master model.[25, 27]

CEREC Omnicam scanner (software version 5.2) was calibrated before taking intraoral impressions. The scan bodies (CARES Mono scan body, Straumann) were hand-tightened onto the multiunit abutments. All scan bodies and the gingiva surrounding the scan bodies were scanned using the intraoral scanner in continuous mode with the circular technique, as described previously.[17, 22] The scanning process started from scan body A and continued until capturing the full anterior span between scan bodies B and C. Then, the scanner tip was turned 180 degrees towards the other quadrant, and the same scan path around the scan bodies on the contralateral side was captured. Ten intraoral scans were performed using the same protocol (IOS group). A standard 5-minute waiting period between scans allowed scanner cooldown.

The intraoral scanner was calibrated once again before extraoral impressions. Each scan body used in the intraoral scanning was hand-tightened to the corresponding analogue on the master model, maintaining the same orientation. Ten scans were performed following a similar scanning procedure as used for intraoral scanning (EIOS group). All the intraoral and extraoral digital scans were conducted by an experienced prosthodontist.

Reference data were acquired by scanning the master model using a high-accuracy industrial scanner (SmartScan-HE Aicon; Hexagone, Stockholm, Sweden). This scanner configuration has 2 separate high-resolution cameras and a blue LED light projector. Its smart data capture technology enables fast acquisition at variable resolutions. Calibration of the reference scanner and evaluation of the reference measurement were performed using a modular software package (Aicon OptoCat; Hexagone), which allows users to configure a setup tailored to their specific measurement requirements. Following the setup and calibration process, it was determined that the device had an accuracy of 2 µm and a consistency rate of 99%.

All scan data were exported to Exocad Dental DB 3.1 (Align Technology, San Jose, California). The scan bodies were replaced with their original ones from the digital library. Subsequently, these modified files were exported to Geomagic Control X (3D Systems Corporation, Rock Hill, South Carolina) software in the standard tessellation language (STL) format for analysis. The accuracy of of intraoral scanner was evaluated by measuring the distances and angles between the scan bodies. The distances between the central points on the upper surface of the scan bodies were measured using the "zero method", as described in previous studies.[12,17,24] The points on the upper surface of the scan bodies were measured using the "zero method", as described in previous studies.[12,17,24] The software tools were utilized to isolate the cylindrical surface and upper plane of the scan bodies. The intersection point between the central axis of the cylinder and the upper plane was identified as the center point. The distances were then measured between the center point of the scan bodies: A-B, A-C, and A-D (**Figure 1**). Similarly, the angulation evaluation was performed by measuring the angles between the central axes of the scan bodies: A-B, A-C, and A-D (**Figure 2**).

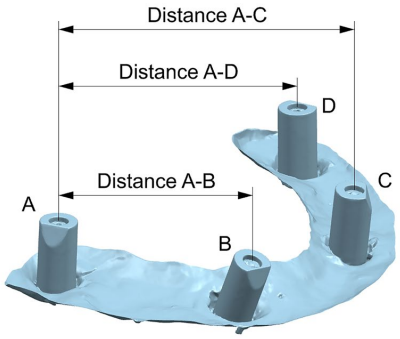

Figure 1. Distance measurement

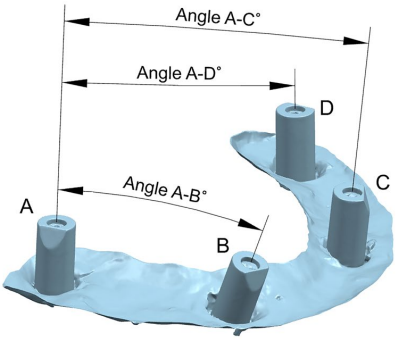

Figure 2. Angulation measurement

For the trueness evaluation, the distance and angular measurements obtained from the IOS and EIOS groups were compared to their respective reference scans, resulting in a total of 30 distance and angulation measurements for each group. The deviations in distance and angle were calculated by subtracting the reference data from the IOS and EIOS data. In the precision evaluation, the measurements of each distance and angulation derived from the 10 scans of the IOS or EIOS groups were compared with each other, resulting in a total of 135 distance and angulation measurements for each group. The deviations in distance and angulation for each measured segment, as well as the mean deviations of all segments (total deviations), were further analyzed as absolute values.[30]

The data were analysed using SPSS v22.0 (IBM Corp, Endicott, New York) software. The normality of the data was evaluated with the Shapiro-Wilk test. Depending on the results, either a paired samples t-test or the Wilcoxon signed-ranks test was conducted to analyse statistically significant differences between groups. A significance level of $p<.05$ was used to determine statistical significance.

RESULTS

The results of the distance trueness for the IOS and EIOS groups are presented in **Figure 3**. The EIOS group exhibited higher distance trueness compared to the IOS group. In the IOS group, the A-B distance had the lowest deviation, while the A-C distance had the highest deviation. In the EIOS group, the distance deviation increased with an deviation. In the EIOS group, the distance deviation increased with an increase in the distance between the scan bodies. The mean total distance deviation (p=.001) and the mean deviation in A-C distance (p<.001) showed a statistically significant difference between the groups. However, there was no significant difference in A-B and A-D distances (**Table 1**).

Figure 4 shows the angle trueness results. In the IOS group, the lowest deviation was in the A-B angulation, while the highest deviation was in the A-C angulation. Mean angle deviations were higher in A-B than in A-C and A-D in the EIOS group. Significant statistical differences were observed in all angle trueness measurements between the IOS and EIOS groups (**Table 1**).

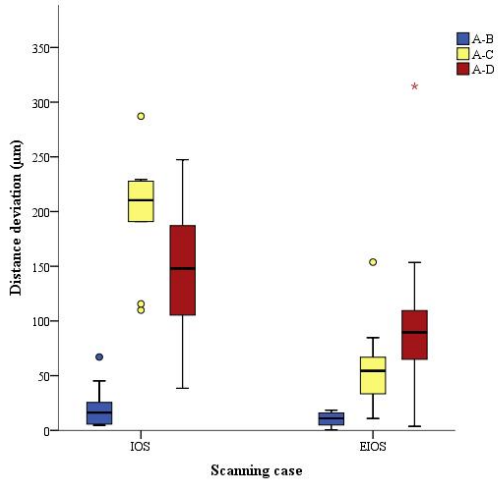

Figure 3. Box plots depicting the medians and interquartile ranges of the distance trueness for each pair of scan bodies in the groups

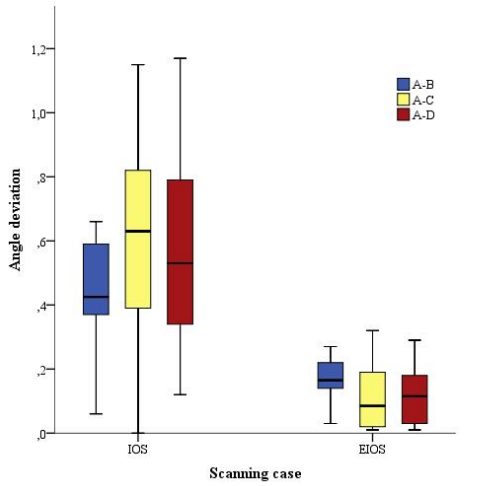

Figure 4. Box plots depicting the medians and interquartile ranges of the angle trueness for each pair of scan bodies in the groups

Table 1. The trueness measurements of distance and angulation in the IOS and EIOS groups

	Distance Deviation (µm)				Angle Deviation			
	Mean±SD	Median(min-max)	t	p	Mean±SD	Median(min-max)	t	p
IOS A-B	21.72 ± 20.18	16.26 (4.67 - 67.04)	-1.275*	.203	0.44 ± 0.18	0.43 (0.06 - 0.66)	4.952†	.001a
EIOS A-B	10.05 ± 6.24	11.05 (0.59 - 18.38)			0.17 ± 0.07	0.17 (0.03 - 0.27)		
IOS A-C	200.06 ± 52.67	210.42 (109.91 - 287.14)	6.403†	<.001a	0.60 ± 0.33	0.63 (0 - 1.15)	4.875†	.001a
EIOS A-C	59.10 ± 39.79	54.38 (10.83 - 153.80)			0.12 ± 0.11	0.09 (0.01 - 0.32)		
IOS A-D	142.82 ± 65.06	148.03 (38.43 - 247.43)	-1.172*	.241	0.57 ± 0.31	0.53 (0.12 - 1.17)	4.023†	.003a
EIOS A-D	104.11 ± 84.52	89.66 (3.67 - 314.66)			0.12 ± 0.09	0.12 (0.01 - 0.29)		
IOS Total	121.53 ± 89.55	117.9 (4.67 - 287.14)	-3.342*	.001a	0.53 ± 0.28	0.52 (0 – 1.17)	7.430†	<.001a
EIOS Total	57.75 ± 65.17	41.23 (0.59 - 314.66)			0.13 ± 0.09	0.14 (0.01 – 0.32)		

Indicates Wilcoxon signed-rank test; †Indicates paired sample t-test; t: Test statistic; aStatistically significant value at p<.05

The results of the distance precision are presented in **Figure 5**. In both groups, the distance precision decreased as the distance between the scan bodies increased. The EIOS group exhibited less distance deviation compared to the IOS group. However, a statistically significant difference was found only in the A-B distance between the groups (p=.002; **Table 2**).

The findings regarding angle precision are illustrated in **Figure 6**. In both groups, the A-B angulation exhibited a lower mean deviation than the A-C and A-D angulations. The EIOS group demonstrated significantly higher precision than the IOS group in all angle deviation measurements (**Table 2**).

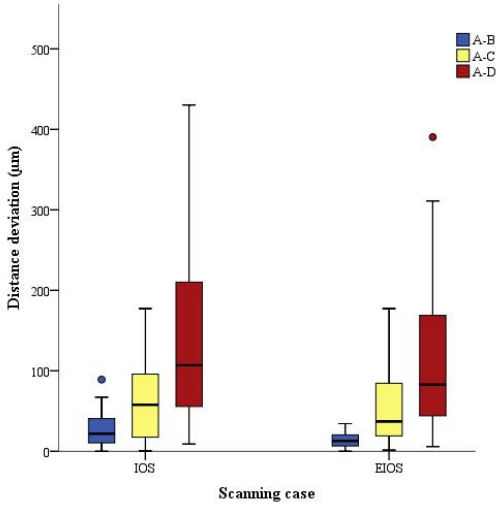

Figure 5. Box plots depicting the medians and interquartile ranges of the distance precision for each pair of scan bodies in the groups

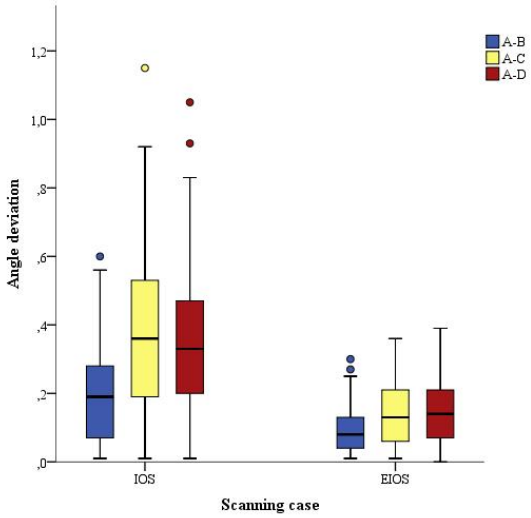

Figure 6. Box plots depicting the medians and interquartile ranges of the angle precision for each pair of scan bodies in the groups

Table 2. The precision measurements of distance and angulation in the IOS and EIOS groups.

	Distance Deviation (µm)				Angle Deviation			
	Mean±SD	Median(min-max)	t	p	Mean±SD	Median(min-max)	t	p
IOS A-B	27.34 ± 21.42	21.83 (0.02 - 89.05)	-3.132*	.002a	0.20 ± 0.15	0.19 (0.01 - 0.60)	-3.455*	.001a
EIOS A-B	14.40 ± 9.10	12.75 (0.03 - 34.33)			0.09 ± 0.07	0.08 (0.01 - 0.30)		
IOS A-C	57.51 ± 47.88	57.76 (0.35 - 177.23)	-0.519*	.604	0.40 ± 0.26	0.36 (0.01 - 1.15)	-4.967*	<.001a
EIOS A-C	52.05 ± 40.97	36.97 (1.45 - 177.26)			0.15 ± 0.10	0.13 (0.01 - 0.36)		
IOS A-D	145.35 ± 112.9	106.93 (8.98 - 430.19)	-0.943*	.346	0.37 ± 0.24	0.33 (0.01 - 1.05)	-4.713*	<.001a
EIOS A-D	112.26 ± 91.47	82.67 (5.81 - 390.39)			0.15 ± 0.09	0.14 (0 - 0.39)		
IOS Total	76.73 ± 87.26	47.61 (0.02 - 430.19)	-1.952*	.051	0.32 ± 0.24	0.27 (0.01 - 1.15)	-7.730*	<.001a
EIOS Total	59.57 ± 70.44	28.86 (0.03 - 390.39)			0.13 ± 0.09	0.11 (0 - 0.39)		

Indicates Wilcoxon signed-rank test; t: Test statistic; aStatistically significant value at p<.05

DISCUSSION

This study analysed the trueness and precision of the CEREC Omnicam scanner for full-arch digital implant impressions in both *in vivo* and *in vitro* conditions. The results indicated that *in vivo* conditions resulted in reduced scanning trueness and precision compared to *in vitro* conditions. A significant difference was observed for most of the evaluated features in both trueness and precision assessments. Therefore,

both the first and second null hypotheses of the study were partially accepted.

This study is the second investigation conducted to evaluate both *in vivo* and *in vitro* accuracy of intraoral scanners for full-arch digital implant impressions. Rutkunas et al.25 observed that the accuracy of the Trios 3 is influenced by intraoral conditions, suggesting that *in vitro* accuracy studies may not fully represent clinical conditions. Similarly, another study found that intraoral scanning of dental arches with the iTero (Align Technologies, San Jose, California) resulted in lower precision compared to model scanning with the same scanner, indicating that intraoral conditions negatively affected the accuracy of the intraoral scanners.[21] Consistent with these previous findings, the current study demonstrated that *in vivo* scans using the CEREC Omnicam exhibited lower accuracy compared to *in vitro* scans.

Obtaining reference measurements for evaluating the *in vivo* accuracy of an intraoral scanner presents a challenge, as direct intraoral scanning with the reference scanner is not possible. Previous studies investigating the *in vivo* accuracy of intraoral scanners have utilized various techniques to transfer implant positions to the master model. These techniques include conventional impression using polyvinylsiloxane,[23] attaching pick-up transfers to a polymethyl methacrylate solid index using type 4 stone,[22] and attaching scan bodies to titanium bars using pattern resin.[20] In our study, titanium cylinders were fixed to the provisional denture using pattern resin, similar to the solid index or titanium bar technique, and the implant positions were transferred to the plaster model. One advantage of this technique is the elimination of errors caused by the distortion of the impression material, as no impression material is used.

The main methodologies used for accuracy measurement include overall 3D deviation measurement with RMS (root mean squared) values of superimposed test and reference scans,[6,8,13-16,18,20,21,25,28] 3D distance errors/angular deviations of scan bodies after superimposition of test and reference scans,[14,22,25,27] and the distance/angular deviations between paired scan bodies without any superimposition.[9,17] In the current study, distance/angular deviations between paired scan bodies without any superimposition were utilized.

There was a trend of increasing distance and angle deviation with greater scanning distance in the EIOS group. Previous studies have also reported similar findings, attributing this trend to the accumulated error during the stitching process.[6,12,21,22,25] However, the highest deviations were generally observed in A-C angles and A-C distances in the IOS group. This could be attributed to the scanning pattern employed. It has been reported that vertical rotation in the anterior region can adversely affect scanning accuracy. In our study, the scanner tip was rotated 180 degrees towards the other quadrant at scan body C. Performing this manipulation in the oral cavity can be more challenging. Therefore, it is possible that more deviation occurred in scan body C, which is the region where the scanner tip is rotated, in the IOS group.

To the best of our knowledge, there are no studies in the literature specifically evaluating the accuracy of the CEREC Omnicam under *in vivo* conditions. However, several *in vivo* studies have evaluated the accuracy of different types of scanners for full-arch implant impressions.[25,27,28] Rutkunas et al.[25] assessed the *in vivo* trueness and precision of distance and angulation between the scan bodies for the Trios 3. Distance trueness deviation varied from 18 ± 7 µm to 32 ± 19 µm (21.72 ± 20.18 µm to 200.06 ± 52.67 µm in the IOS group in the present study). Distance precision deviation ranged from 10 ± 3 µm to 44 ± 18 µm (27.34 ± 21.42 µm to 145.35 ± 112.9 µm in the IOS group in the present study). Angle trueness deviation varied from 0.07 ± 0.05 to 0.18 ± 0.10 (0.44 ± 0.18 to 0.57 ± 0.31 in the IOS group in the present study). Angle precision deviation varied from 0.11 ± 0.05 to 0.22 ± 0.14 (0.2 ± 0.15 to 0.37 ± 0.24 in the IOS group in the present study). Mandelli et al.[27] reported a mean distance trueness deviation of 240 ± 80 µm to 800 ± 230 µm for the True Definition. Chochlidakis et al.[28] found a mean 3D trueness deviation (RMS) of 162 ± 77 µm for the True Definition. It is important to note that direct comparisons between these results and the present study are not possible due to variations in the evaluated scanners and the methodology used for accuracy measurement. However, Andriessen et al.[25] reported that an angle deviation of approximately 0.4 degrees and a distance deviation of 100 µm between two implants are considered clinically acceptable limits. In this study, the mean distance trueness was 121.53 ± 89.55 µm, with a maximum distance trueness of 287.14 µm in the IOS group. The mean angle trueness was 0.53 ± 0.28 degrees, with a maximum angle trueness of 1.17 degrees. These results indicate that the trueness deviation of the CEREC Omnicam scanner is above the recommended clinically acceptable limit for full-arch implant impression.

Several *in vitro* studies have been conducted to evaluate the accuracy of the CEREC Omnicam for full-arch implant impressions.[6,8,11,13,14] It reported that the 3D trueness deviation (RMS) ranged from 46.41[8] to 61 µm[13] and the 3D precision deviation (RMS) ranged from 19[6] to 59 µm[13] for the CEREC Omnicam. Albayrak et al.[11] investigated the trueness and precision of intraoral scanners for the edentulous mandible model with eight implants. They reported mean distance trueness of 229.72 µm (57.75 µm in the EIOS group in the present study), a mean distance precision of 94.06 µm (59.57 µm in the EIOS group in the present study), mean angle trueness of 0.53 degrees (0.13 degrees in the EIOS group in the present study), and a mean angle precision of 0.30 degrees (0.13 degrees in the EIOS group in the present study) for the CEREC Omnicam. Differences in the number of implants in the models and the methodology used to measure accuracy may contribute to the variations in the results obtained.

The limitations of this study include the use of only one intraoral scanner and the fact that digital impressions were taken from a single patient. However, it is worth noting that *in vitro* studies in the literature also scanned a single plaster model, making this study comparable to other existing studies.[6,8,11,13,14] Nevertheless, additional clinical studies are necessary to evaluate the accuracy of intraoral scanners for full-arch implant impressions in diverse patient populations.

CONCLUSION

Within the limitations of this study, the following conclusions were reached: Full-arch digital implant impressions performed *in vivo* exhibited lower accuracy compared to those conducted *in vitro*. The accuracy of full-arch digital implant impressions made with the Cerec Omnicam under *in vivo* conditions was found to be below the previously reported clinically acceptable limit.

Değerlendirme / Peer-Review

İki Dış Hakem / Çift Taraflı Körleme

Etik Beyan / Ethical statement

Bu çalışmanın hazırlanma sürecinde bilimsel ve etik ilkelere uyulduğu ve yararlanılan tüm çalışmaların kaynakçada belirtildiği beyan olunur.

It is declared that during the preparation process of this study, scientific and ethical principles were followed and all the studies benefited are stated in the bibliography.

Benzerlik Taraması / Similarity scan

Yapıldı – ithenticate

Etik Bildirim / Ethical statement

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Finansman / Grant Support

Yazarlar bu çalışma için finansal destek almadığını beyan etmiştir. | The authors declared that this study has received no financial support.

Çıkar Çatışması / Conflict of Interest

Yazarlar çıkar çatışması bildirmemiştir. | The authors have no conflict of interest to declare.

Yazar Katkıları / Author Contributions

Çalışmanın Tasarlanması | Design of Study: TS (%60) EE(%20) EY(%20)
Veri Toplanması | Data Acquisition: TS (%30) EE (%35) EY (%35)
Veri Analizi | Data Analysis: TS(%40) EE (%30) EY (%30)
Makalenin Yazımı | Writing up: TS (%60) EE (%20) EY (%20)
Makale Gönderimi ve Revizyonu | Submission and Revision: TS (%80) EE (%10) EY (%10)

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