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Original Research Article

Effect of Intraoral Scanner on The Scan Accuracy of Different Restoration Designs

Ağız İçi Tarayıcıların Farklı Restorasyon Tasarımlarının Tarama Doğruluğuna Etkisi

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ABSTRACT

Aim: The aim of this *in vitro* study was to evaluate the effect of intraoral scanners (IOS) and preparation design on the scan accuracy of different clinical situations.

Materials and Method: Three different dental models of inlay, onlay, and crown preparation designs were used. Reference scans were performed with an industrial-grade scanner (ATOS Core 80, GOM), while each model was scanned 10 times with Trios 4 (3Shape), Trios 3 (3Shape), Primescan (Dentsply Sirona), Omnicam (Dentsply Sirona), Emerald (Planmeca), and Medit i700 (Medit Corp). All scans were exported as standard tessellation language files, and imported into a 3D analysis software (Geomagic Control X 2020.1) to evaluate the trueness and the precision of the scans. Two-way analysis of variance and post-hoc Tukey HSD tests were used to analyze data (α=0.05).

Results: Tested intraoral scanners and preparation designs affected the scan accuracy. Medit i700 and crown scans had the highest trueness. Crown scans had the lowest precision within each IOS, except for Trios 4. Intraoral scanners did not affect the precision of the scans.

Conclusion: It should be considered that the trueness and precision of the preparations with complex geometries may decrease depending on the IOS used.

Keywords: Accuracy; Intraoral scanner; Digital dentistry; Preparation design

ÖZET

Amaç: Bu *in vitro* çalışmanın amacı, farklı ağız içi tarayıcılar ile gerçekleştirilen preparasyon dizaynlarının taramaların doğruluk ve keskinliği üzerindeki etkisini değerlendirmektir.

Gereç ve Yöntem: Çalışmada inley, onley ve tam kron preparasyon dizaynlarına ait 3 ayrı dental model kullanıldı. Referans taramalar, endüstriyel tip tarayıcı (ATOS Core 80, GOM) ile gerçekleştirilidi. Ardından her model Trios 4 (3Shape), Trios 3 (3Shape), Primescan (Dentsply Sirona), Omnicam (Dentsply Sirona), Emerald (Planmeca) ve Medit i700 (Medit Corp) ağız içi tarayıcılar ile 10'ar defa tarandı. Tüm tarama verileri standart üçgenleme dili (standard tessellation language) formatına dönüştürüldü ve 3D analiz yazılımında (Geomagic Control X 2020.1) çakıştırılarak doğruluk ve keskinlik değerleri hesaplandı. Bu değerler iki yönlü varyans analizi ve post hoc Tukey testleri ile incelendi (α=0.05).

Bulgular: Ağız içi tarayıcılar ve preparasyon dizaynları tarama hassasiyetini etkilemiştir. Medit i700 ve kron tipi preparasyonlar en yüksek tarama doğruluğu göstermiştir. Kron preparasyon taramaları, Trios 4 tarayıcı hariç bütün tarayıcılarda en düşük keskinliği göstermiştir. Ağız içi tarayıcılar tarama keskinliğini etkilememiştir.

Sonuç: Karmaşık geometrilere sahip preparasyonlarda doğruluk ve hassasiyetin, kullanılan ağız içi tarayıcıya da bağlı olarak azalabileceği göz önünde bulundurulmalıdır.

Anahtar Kelimeler: Ağıziçi tarayıcılar; Dijital diş hekimliği; Preparasyon dizaynı

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INTRODUCTION

In recent years, developments in digital technologies provided many conveniences to clinicians in routine applications.[1] Digital technologies offer various advantages at every stage of treatment, from diagnosis and planning to impression, design, and production.[2] Features such as increased patient comfort, reduced treatment time, and prevention of distortions have enabled digital applications to be widely accepted.[3,4] Increased material diversity has also contributed to the integration of digital systems into clinical practice.[5] Moreover, thanks to these developments, hard and soft tissues can easily be digitized by using intraoral scanners (IOSs) and the success of prosthetic process has increased.[6]

Following diagnosis and planning, the most important stage of digital dentistry in prosthetic applications is intraoral scanning.[7] Intraoral scan data is transferred into a dental design program or transmitted directly to the laboratory to initiate the prosthesis fabrication.[8] At this stage, prosthetic success is directly related to the accuracy and reliability of the impression.[9] The concepts of trueness and precision, which are combined for accuracy, in digital measurements are evaluated according to ISO5725-1 standards.[10] Trueness describes the closeness of a measured value to the actual dimensions, while precision refers to the consistency or repeatability of measured values.[11] Trueness of a scan is directly related to the scanner-, environment-, and restoration-related factors.[12,13] Previous studies have shown that the trueness and precision are also affected by factors such as the type of restoration, the position of the teeth or implant, and the size of the scan area.[14-16] In addition, factors such as preparation depth, margin thickness, scanning strategy[17-19] also affect the scan accuracy.[7] Current systems offer adequate scan accuracy similar to that of conventional impressions, and fabricated restorations have adequate fit.[20] However, it has been reported that the preparation type is associated with the scan accuracy even in single-unit restorations.[21] While there are some studies on the effect of different restoration geometries on scan accuracy, the data on the effect of current IOSs are insufficient.[22,23] Therefore, the aim of this study was to evaluate the scan accuracy of different clinical situations (inlay, onlay, and full crown) when different IOSs are used. The null hypothesis was that different IOSs and preparation designs would not affect the trueness and precision of the scans.

MATERIALS AND METHOD

The present study was performed with maxillary partial-arch models with 3 different preparation geometries. The right first molar tooth was prepared for an inlay, the left first premolar for an onlay, and the left canine tooth for a complete crown. The inlay preparation had a mesiooclusal design with shoulder finish line at the gingival margin and the preparation width was 1/3 of the buccolingual width. The onlay preparation had a mesioocclusodistal design with 1.5 mm reduction from the lingual and 1 mm reduction from the buccal cusp. Complete crown was prepared with a 1 mm-thick shoulder margin. A single operator (M.D.) performed all preparations. Each partial-arch model was digitized with an industrial scanner (Atos Core 80 5M; GOM GmbH, Braunschweig, Germany) to generate the reference standard tessellation language (STL) files.

Six different IOSs [Trios 4 (3Shape, Copenhagen, Denmark), Trios 3 (3Shape, Copenhagen, Denmark), Primescan (Dentsply Sirona, Bensheim, Germany), Omnicam (Dentsply Sirona, Bensheim, Germany), Planmeca Emerald (Planmeca Oy, Helsinki, Finland), Medit i700 (Medit Corp, Seoul, South Korea)] were then used to digitize each model 10 times. These scan files were imported in STL format. The same operator who performed the preparations also performed the IOS scans in line with manufacturers' recommendations in the same room under 1000 lux room light. The number of specimens in each group (n = 10) was decided based on a priori power analysis with 0.05 confidence (1-α), 95% test power (1-β),

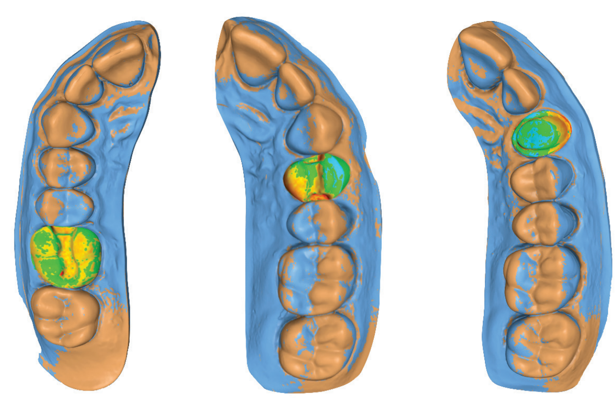

Figure 1. Color maps generated after superimpositions

and f = 0.64 effect size by using a software (G*Power, 3.1.9.2; University of Dusseldorf, Dusseldorf, Germany).

For the 3-dimensional (3D) comparative analyses, all of the data was imported into a 3D analysis software (Geomagic Control X 2020.1, Rock Hill, SC, USA). The prepared tooth was isolated within each STL file and the STLs generated from IOS scans were superimposed over those generated from reference scanner scans by using the best-fit alignment method. Surface deviations were automatically calculated by using the root mean square method (Fig. 1). The normality of the data was examined with the Shapiro-Wilk test. Due to the normal distribution for all three different models, the data was analyzed by using software with 2-way analysis of variance (ANOVA) (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) Multiple comparisons were performed with the post-hoc Tukey HSD test (α=0.05).

RESULTS

Two-way ANOVA results of the trueness of the scans are presented in Table 1. Table 2 shows the descriptive statistics of measured deviations for each IOS-preparation design pair. The IOS (p<0.001), preparation design (p<0.001), and their interaction (p=0.008) affected the trueness of the scans. When the IOSs were considered, Omnicam had the lowest trueness, which was followed by Trios 3. However, the difference between Omnicam and Trios 3 was nonsignificant (p=0.069). Medit i700 had higher trueness than the remaining IOSs (p<0.05), other than Trios 4. (p=0.603) (Fig 2.). There was no significant difference among the trueness of Planmeca, Primescan, and Trios 3 scans (p=0.755). There was no statistically significant difference between inlay and onlay designs (p=0.325). However, crown scans had significantly higher trueness than those of other preparations (p<0.001).

Two-way ANOVA results of the precision of the scans are presented in Table 3 and Table 4 shows the descriptive statistics of the deviations when the precision is considered. According to the analyses, it was seen that the preparation type affected the precision of the scans (p<0.001), whereas IOS (p=0.266) the interaction between the main factors (p=0.300) did not affect each other. Scans of the crown preparation had the lowest precision (p<0.001), while those of other preparations had similar precision (p=0.708). The highest RMS values in terms of precision were seen in the Inlay models, followed by onlay and full crown preparations, respectively. Statistically significant highest precision was seen in full crown in all scans except Trios 4 (p<0.001).

Table 1. Two-way ANOVA Analysis for Trueness.

Source	Type III Sum of Squares	Df	Mean Square	F	*P*	Partial Eta Squared
Corrected Model	10754.222	17	632.601	8.620	.000	.671
Intercept	318027.778	1	318027.778	4333.460	.000	.984
Preparation	1308.156	2	654.078	8.912	.000	.198
IOS	7506.889	5	1501.378	20.458	.000	.587
Preparation * IOS	1939.178	10	193.918	2.642	.008	.268

df: Degree of Freedom; IOS: Intraoral Scanner

Table 2. Descriptive Analysis for Measured Deviations (Trueness in µm).

		Trios 4	Trios 3	Primescan	Omnicam	Planmeca	Imedit700
Inlay	**RMS**	49.8^{aA}	57.2^{aBC}	73.6^{aBC}	81^{aC}	62.2^{aB}	41.2^{aA}
	SD	4.26	11.34	7.56	11.42	8.55	5.97
Onlay	**RMS**	52.8^{aA}	70^{aBC}	64^{aBC}	76.2^{aC}	61.6^{aB}	51.8^{aA}
	SD	6.72	9.97	3.8	7.88	3.13	10.01
Full Crown	**RMS**	45.6^{bA}	66.2^{bBC}	50.8^{bBC}	59^{bC}	58.6^{bB}	42.2^{bA}
	SD	5.12	5.89	1.30	9.51	3.97	4.26

RMS: Root Mean Square; SD: Standard Deviation. Different superscript letters (lowercase for columns and uppercase for rows) indicate statistical significance (P<0.05).

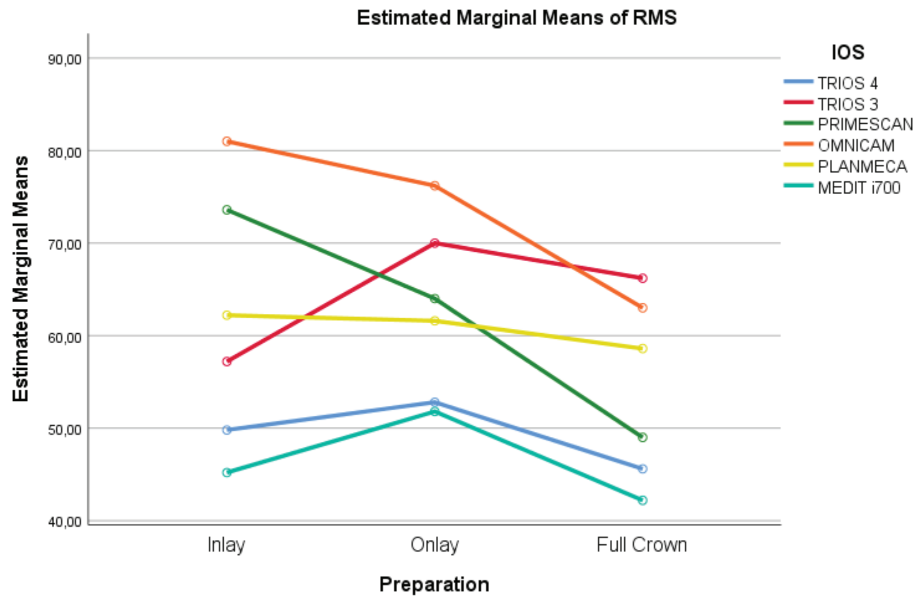

Figure 2. Line plot of measured deviations for each intraoral scanner-preparation design pair.

Table 3. Two-way ANOVA Analysis for Precision.

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial Eta Squared
Corrected Model	376.356[a]	17	22.139	2.900	.001	.406
Intercept	2646.044	1	2646.044	346.643	.000	.828
Preparation	233.756	2	116.878	15.311	.000	.298
IOS	50.356	5	10.071	1.319	.266	.084
Preparation * IOS	92.244	10	9.224	1.208	.300	.406

df: Degree of Freedom; IOS: Intraoral Scanner

Table 4. Descriptive Analysis for Measured Deviations (Precision in µm).

		Trios 4	Trios 3	Primescan	Omnicam	Planmeca	Imedit700
Inlay	**RMS**	5[a]	7.4[a]	6[a]	6.6[a]	7[a]	9[a]
	SD	4.3	3.43	3.53	3.91	2.91	0.7
Onlay	**RMS**	3[a]	7.4[a]	6.4[a]	6.2[a]	7[a]	7.6[a]
	SD	2.91	1.34	2.88	3.42	3.46	1.51
Full Crown	**RMS**	4.4[a]	4.2[b]	2.4[b]	3[b]	3.2[b]	1.8[b]
	SD	1.51	3.56	0.89	2.34	1.78	1.09

RMS: Root Mean Square; SD: Standard Deviation. Different superscript letters (lowercase for columns) indicate statistical significance (P<0.05).

DISCUSSION

The present study aimed to evaluate how different IOSs and preparation designs affected the scan accuracy of different clinical situations. The trueness of the scans was affected by both parameters and the interaction between them, while the precision of the scans was only affected by the preparation design. Therefore, the null hypothesis that the IOS and preparation design would not affect the trueness and precision of the scans was rejected.

Analyzing the preparation types, it was seen that the RMS values of the full crown design were significantly lower than the inlay and onlay restorations. Accordingly, it was concluded that the scans of the complete crown design had the highest trueness. Carbajal *et al*[24] reported that the preparations with different geometries affected the accuracy of the scans. In another similar study, it was observed that the preparation design affected the trueness and precision of IOSs, consistent with the results of the present study.[25]

When the effect of IOS on the trueness of inlay preparation scan trueness was considered, Medit i700 and Trios 4 had the highest trueness. In addition, Omnicam had lower trueness than Planmeca. These results are parallel to those of onlay and complete crown preparations. The IOSs tested in the present study have different data acquisition methods.[26] This may explain the fact that IOSs have different deviation values on different preparation designs. Although both systems use the photo-video imaging technique, the PrimeScan uses triangulation active working principle, while the Trios 4 uses confocal microscopy.[27] Different accuracy values for different scanners have been reported in previous studies.[7,28] Similar to this study, Omnicam, Trios 3, and Medit i500 were used in a study evaluating the effect of different preparation geometries on scanning accuracy. The researchers concluded that the less complex preparation geometries had higher accuracy values, which is consistent with our study.[7]

When the precision of the scans of tested IOSs in different preparation designs was considered, it was observed that there was no significant difference among IOSs. However, preparation designs affected the precision of the scans within each IOS except Trios 4. Considering these findings, it can be hypothesized that more complex preparation designs may reduce the scan accuracy. However, the similarity between scanners in precision measurements may be explained by the fact that the study was performed *in vitro*, independent of factors such as intraoral humidity and patient mobility.[9]

Previously, it has been reported that the properties of the model, the light transmittance of the scanning region and the ambient light affect the scanning accuracy.[29]

A limitation of the present study was that the scans were performed on a typodont model. Therefore, patient-related factors such as gagging, limited mouth opening, and the presence of saliva and blood could not be simulated. It should also be mentioned that typodont teeth do not have similar optical properties to those of natural dental tissues. In addition, the present study was limited to single-unit restorations and longer-span preparations may lead to different results. Best fit algorithm was used to register the obtained images. In order to make the most accurate comparison during the alignment phase, the iterative closest point algorithm was preferred, in line with previous studies.[14,30] However, there are different superimposition algorithms (Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment)[27], which may affect the results. Finally, different locations were not taken into account while evaluating the preparation design. Planning further *in vivo* studies to better reflect clinical conditions will provide more realistic results.

CONCLUSION

Based on the findings and limitations of this study, the following conclusions can be drawn:

1. Scan accuracy of tested clinical situations is affected by preparation designs, while tested intraoral scanners only affected the trueness of the scans.
2. When evaluating different preparation geometries, simple geometries have higher scanning accuracy
3. While different intraoral scanners have no effect on scanning accuracy, restoration geometry may affect accuracy.

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