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The Effects of Different Restoration Materials on the Trueness of Intraoral Scanners

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ABSTRACT

Aim: This study aimed to assess how different restoration materials affect the trueness of intraoral scanners.
Materials and Methods: Artificial teeth on a typodont model were prepared for crowns and fixed partial dentures (FPDs) using full metal, monolithic zirconia, and porcelain-fused-to-metal (PFM) materials. Each group underwent 10 scans with a Trios intraoral scanner, generating 60 STL files. A reference scanner created a master model using scanning spray to reduce reflection errors. The STL files were aligned with reverse engineering software for comparison and were analyzed in micrometers (µm) using Root Mean Square (RMS) and Mean Distance measurements. The Levene test and two-way ANOVA with Post Hoc analysis were used for statistical evaluation.
Results: The RMS deviations for the FPDs were 77.9 ± 15.2 µm (full metal), 84.6 ± 6.9 µm (monolithic zirconia), and 130 ± 19.7 µm (PFM). For the crowns, the RMS values were 76.9 ± 6.5 µm (metal), 71 ± 8.2 µm (monolithic zirconia), and 153 ± 22.4 µm (PFM). The mean distance deviations for the FPDs were 11.4 ± 4.8 µm (metal), 11.2 ± 3.4 µm (monolithic zirconia), and 18.3 ± 2.6 µm (PFM). For the crowns, the mean distances were 8.6 ± 3.4 µm (metal), 10.2 ± 3 µm (monolithic zirconia), and 24.7 ± 3.3 µm (PFM). Significant differences were noted in the PFM groups.
Conclusion: Restoration materials notably affected intraoral scanner trueness, especially PFM restorations. The restoration length did not significantly affect the accuracy.

Farklı Restorasyon Materyallerinin Ağız İçi Tarayıcı Doğruluğuna Etkisi

Makale Bilgisi

Makale Geçmişi

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ÖZET

Amaç: Bu çalışma, farklı restorasyon malzemelerinin ağız içi tarayıcıların doğruluğunu nasıl etkilediğini değerlendirmiştir.
Gereç ve Yöntemler: Bir tipodont model üzerindeki yapay dişler, tam metal, monolitik zirkonya ve metal destekli porselen malzemeleri kullanılarak kron ve sabit bölümlü protez için prepare edildi. Her grup, Trios ağıziçi tarayıcı ile on kez tarandı ve toplamda 60 STL dosyası oluşturuldu. Yansımayı azaltmak için tarama spreyi kullanılarak bir referans tarayıcı ile ana model oluşturuldu. STL dosyaları tersine mühendislik yazılımı ile hizalanarak karşılaştırıldı ve mikrometre (µm) cinsinden Kök Ortalama Kare (RMS) ve Ortalama Mesafe ölçümleri ile analiz edildi. İstatistiksel değerlendirme için Levene testi ve iki yönlü ANOVA ile Post Hoc analizi kullanıldı.
Bulgular: Köprü restorasyonlar için RMS sapmaları metalde 77,9 ± 15,2 µm, monolitik zirkonyada 84,6 ± 6,9 µm ve porselende 130 ± 19,7 µm olarak bulundu. Kronlar için RMS değerleri tam metalde 76,9 ± 6,5 µm, monolitik zirkonyada 71 ± 8,2 µm ve porselende 153 ± 22,4 µm bulundu. Köprü restorasyonlar için Ortalama Mesafe sapmaları metalde 11,4 ± 4,8 µm, monolitik zirkonyada 11,2 ± 3,4 µm ve porselende 18,3 ± 2,6 µm olarak bulundu. Kronlar için Ortalama Mesafe değerleri metalde 8,6 ± 3,4 µm, monolitik zirkonyada 10,2 ± 3 µm ve porselende 24,7 ± 3,3 µm bulundu. Porselen gruplarında anlamlı farklılıklar gözlendi.
Sonuç: Restorasyon malzemeleri, özellikle metal destekli porselen restorasyonlarında ağız içi tarayıcıların doğruluğunu önemli ölçüde etkilemektedir. Restorasyon uzunluğu, doğruluk üzerinde önemli bir etki göstermemiştir.

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INTRODUCTION

From the past to the present, various impression materials and impression techniques have been developed for use in the fabrication of dental prostheses. These materials facilitate the accurate transfer of hard and soft tissues from the patient's oral cavity to the laboratory setting. The accuracy and functionality of the restoration depend on the precise replication of the impression in these tissues. The impression must scan the intraoral tissues accurately to produce well-fitting restorations.[1]

The use of digital impressions, which have been increasingly prevalent in recent years, began in dentistry in the 1980s.[2] Digital impressions allow for simultaneous treatment planning, restoration fabrication, previewing of treatment stages, and visually presenting the anticipated treatment outcomes to the patient at the chairside.[3] The increasing practicality, speed, and accuracy of intraoral scanners have contributed to their widespread adoption.[4] However, the accuracy of evolving digital impression systems can vary depending on the intraoral fluids, scanning methods, and surface being scanned.[5]

Two factors influence impression accuracy: trueness and precision. Trueness refers to how closely the impression resembles the actual dimensions of the intraoral environment, while precision denotes the consistency between repeated impressions. High accuracy requires consistent and accurate digital impressions that reflect the intraoral environment.[6]

In the early stages of digital impressions, the use of titanium dioxide powder and similar materials before scanning reduced patient satisfaction. The interaction of the powder with saliva often necessitated reapplication, and excessive accumulation of the powder on the surface led to inaccurate measurements. These issues contributed to the reluctance of dental professionals to adopt such methods.[7] The purpose of powder-based systems was to ensure that surfaces scanned in the oral environment possessed uniform color and opacity, thereby preventing errors caused by light reflections.[8]

The newly developed dust-free systems offer enhanced comfort for patients and ease of use for dentists.[9] The oral cavity contains restorations made from various materials, such as composite, amalgam, zirconia, and metal crowns, each of which exhibits different light transmission and reflection properties.[10] Intraoral scanners utilize light to capture the oral cavity environment. The Trios system is a scanner equipped with structured light imaging technology, confocal microscopy, and rapid optical scanning capabilities.[11] Confocal microscopy is an optical imaging technique that employs spatial filtering to eliminate light/brightness outside the focal plane, thereby enhancing contrast and generating 3D images.[12]

The properties of scanned surfaces, such as light reflection, refraction, and translucency, significantly influence the path followed by light from the scanner to the sensor.[5] This study aimed to investigate the effect of materials with different surface properties and lengths on the accuracy of teeth prepared using the Trios intraoral scanner. The null hypothesis of the study was that different materials did not affect the accuracy of the intraoral scanner.

MATERIAL AND METHODS

To standardize the scans, a typodont model (Frasaco model, Frasaco, Tettnang, Germany) was divided into two groups: crowns and fixed partial dentures (FPDs). Each group was further divided into three subgroups for the production of restorations (Figure 1). For single crown restorations, the maxillary second molar was prepared. Using a desktop scanner, the following crown restorations were produced: M1: Metal (Cr-Co), P1: Porcelain fused to metal (Ivoclar Vivadent), Z1: Monolithic zirconia (Aidite 3D Pro Zir). The second molar and second premolar teeth were prepared for the FPDs. The following FPD restorations were produced: M3: metal (Cr-Co); P3: Porcelain fused to metal (Ivoclar Vivadent); and Z3: monolithic zirconia (Aidite 3D Pro Zir). Porcelain crowns and FPDs were glazed, while zirconia and metal restorations underwent mechanical polishing. The materials used are listed in Table 1.

Figure 1: Prepared models with restorations

Table 1: Materials used in the study

Groups	Metal (M)		Monolithic Zirconia (Z)		Porcelain (P)	
Subgroups	Metal Crown (M1)	Metal FPD (M3)	Zirconia Crown (Z1)	Zirconia FPD (Z3)	Porcelain Crown (P1)	Porcelain FPD (P3)
Producer	-	-	Aidite 3D Pro Zir	Aidite 3D Pro Zir	Ivoclar Vivadent	Ivoclar Vivadent
Materials Description	Cr-Co	Cr-Co	Multilayer Monolithic	Multilayer Monolithic	Feldspathic	Feldspathic
Finishing Methods	Polishing	Polishing	Polishing	Polishing	Glazing	Glazing

The designed restorations were cemented into the model using polycarboxylate cement (Carbofine Polycarboxylate, Pentron, SPOFA Dental) to secure them in place. The prepared models were scanned using a reference scanner (SHINING 3D AutoScan-DS-MIX Dental 3D Scanner) to obtain the reference model. Each group was scanned 10 times using a Trios 3 intraoral scanner system (3Shape, Copenhagen, Denmark), following the manufacturer's recommended scanning method to ensure standardization. All scans were performed by the same operator to maintain consistency. In total, 60 STL files were generated (Figure 2).

Figure 2: Scanning and analysis process

The obtained STL files were imported into reverse engineering software (CloudCompare v2.13.1 for Mac) and extraneous data points were removed to refine the model. To assess accuracy, the STL data of the reference model were aligned with the STL data obtained from the intraoral scanner within each group using the best-fitting alignment, followed by a comparison (Figure 2).

The software uses the iterative closest point algorithm for optimal alignment. The color-coded images of the model indicate areas of deviation: blue areas denote negative or inward deviation, and red areas signify positive or outward deviation. The increasing intensity of the color was correlated with the magnitude of the deviation.

Accuracy was quantified as the root mean square (RMS) deviation. When comparing two scans, the squares of the differences in the x, y, and z axes of the points where deviation occurred were calculated. The sum of these squares was divided by the number of points, and the root mean square was determined as the square root of this value. In addition, the average differences between the aligned models were calculated.

Statistical Analysis

The results were analyzed using a statistical program (IBM SPSS Statistics 29.0.1). Normality of the groups was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated using the Levene test. Based on the results, a two-way ANOVA was conducted. The post hoc Tukey test was applied to evaluate the differences between groups.

RESULTS

The results suggest that the findings of this study are highly intriguing. The presence of homogeneous variances and normally distributed data provides a robust foundation for statistical analysis. The two-way ANOVA revealed significant differences among the groups, with the post hoc Tukey test identifying significant differences between the porcelain group and the other groups. Additionally, it is noted that the length factor alone does not have a significant effect, whereas material does. The interaction between length and material is also significant, indicating that the effect of the material depends on the length. These findings underscore the significant impact of different materials and lengths used in dental restorations on their accuracy.

Tables 2 and 3 present the averages and standard deviations, expressed in micrometers (µm), resulting from the examination of the accuracy of six different restorations using the RMS method and the distance difference method. A lower mean value indicates less deviation from the reference, which indicates higher accuracy. An examination of the RMS values revealed that the porcelain crown and porcelain FPD groups exhibited the lowest accuracy, with values of 153 ± 22.4 µm and 130 ± 19.7 µm, respectively. Similarly, when examining the distance difference, the same groups had the lowest accuracy values with values of 24.7 ± 3.3 µm and 18.3 ± 2.6 µm, respectively. Different lowercase letters indicate significant differences between groups ($p < 0.05$). Table 4 illustrates the mean differences between the restoration groups according to the RMS method, and Table 5 shows the mean differences according to the distance difference method.

Table 2: Rms values

Materıal	Restoration	N	RMS (µm)	Standard Deviation (µm)
Metal	Crown	10	76.9 [a]	6.5
	FPD	10	77.9 [a]	15.2
Porcelain	Crown	10	153 [b]	22.4
	FPD	10	130 [c]	19.7
Zirconia	Crown	10	71 [a]	8.2
	FPD	10	84.6 [a]	6.9

($p<0.05$, different lowercase letters exhibited significant differences. FPD: Fixed partial denture. Mean and standard deviation of the RMS values obtained from the analysis of the groups)

Table 3: Mean distances

Materıal	Restoration	N	RMS (µm)	Standard Deviation (µm)
Metal	Crown	10	8.6 a	3.4
	FPD	10	11.4 a	4.8
Porcelain	Crown	10	24.7 b	3.3
	FPD	10	18.3 c	2.6
Zirconia	Crown	10	10.2 a	3
	FPD	10	11.2 a	2.4

($p<0.05$, different lowercase letters exhibited significant differences. FPD: Fixed partial denture. Mean and standard deviation of the distance differences obtained from the analysis of the groups)

Table 4: Comparison of RMS

Material		Mean Difference	P-Adj	Lower	Upper
M3	P3	0.053	P<0.001	0.0326	0.0733
M3	M1	-0.001	P>0.05	-0.0214	0.0194
M3	P1	0.0752	P<0.001	0.0548	0.0956
M3	Z1	-0.007	P>0.05	-0.0274	0.0134
M3	Z3	0.0067	P>0.05	-0.0137	0.027
P3	M1	-0.054	P<0.001	-0.0744	-0.0336
P3	P1	0.0222	P<0.05	0.0018	0.0426
P3	Z1	-0.06	P<0.001	-0.0803	-0.0396
P3	Z3	-0.0463	P<0.001	-0.0667	-0.0259
M1	P1	0.0762	P<0.001	0.0558	0.0966
M1	Z1	-0.006	P>0.05	-0.0264	0.0144
M1	Z3	0.0077	P>0.05	-0.0127	0.0281
P1	Z1	-0.0822	P<0.001	-0.1026	-0.0618
P1	Z3	-0.0685	P<0.001	-0.0889	-0.0481
Z1	Z3	0.0137	P>0.05	-0.0067	0.034

(M1: Metal crown, Z1: Zirconia crown, P1: Porcelain crown, M3: Metal fixed partial denture, Z3: Zirconia fixed partial denture, P3: Porcelain fixed partial denture. Mean difference, p-value, and upper and lower values obtained from the comparison of RMS between groups)

Table 5: Comparison of mean distances

Material		Mean Difference	P-Adj	Lower	Upper
M3	P3	0.0069	<0.05	0.0019	0.0118
M3	M1	-0.0028	>0.05	-0.0077	0.0021
M3	P1	0.0133	<0.001	0.0084	0.0183
M3	Z1	-0.0012	>0.05	-0.0062	0.0037
M3	Z3	-0.0002	>0.05	-0.0052	0.0047
P3	M1	-0.0097	<0.001	-0.0146	-0.0048
P3	P1	0.0064	<0.05	0.0015	0.0114
P3	Z1	-0.0081	<0.05	-0.013	-0.0032
P3	Z3	-0.0071	<0.05	-0.012	-0.0022
M1	P1	0.0161	<0.001	0.0112	0.0211
M1	Z1	0.0016	>0.05	-0.0033	0.0065
M1	Z3	0.0026	>0.05	-0.0024	0.0075
P1	Z1	-0.0145	<0.001	-0.0195	-0.0096
P1	Z3	-0.0135	<0.001	-0.0185	-0.0086
Z1	Z3	0.001	>0.05	-0.0039	0.0059

(M1: Metal crown, Z1: Zirconia crown, P1: Porcelain crown, M3: Metal fixed partial denture, Z3: Zirconia fixed partial denture, P3: Porcelain fixed partial denture. Mean difference, p-value, and upper and lower values obtained from the comparison of distance differences between groups)

In the two-way ANOVA, the p-value for the crown FPD factor was 0.53, indicating no significant difference between restoration lengths. The p-value for material factor was approximately <0.0001, indicating a significant difference between the material types. The p-value for the interaction between restoration length and material factor was 0.002, suggesting a significant interaction between restoration length and material factors. Thus, while restoration length alone is not a significant factor, it can influence the results depending on the material. Post hoc analysis revealed significant differences between the porcelain and other groups.

Color Analysis

Figure 3 shows deviations resulting from the overlay of metal crowns, porcelain crowns, zirconia crowns, metal FPD, porcelain FPD, and zirconia FPD on a color map. Red and blue colors indicate positive and negative deviations, respectively. While all groups exhibited deviations in the restoration area, the porcelain crown group exceeds the value of 150 µm.

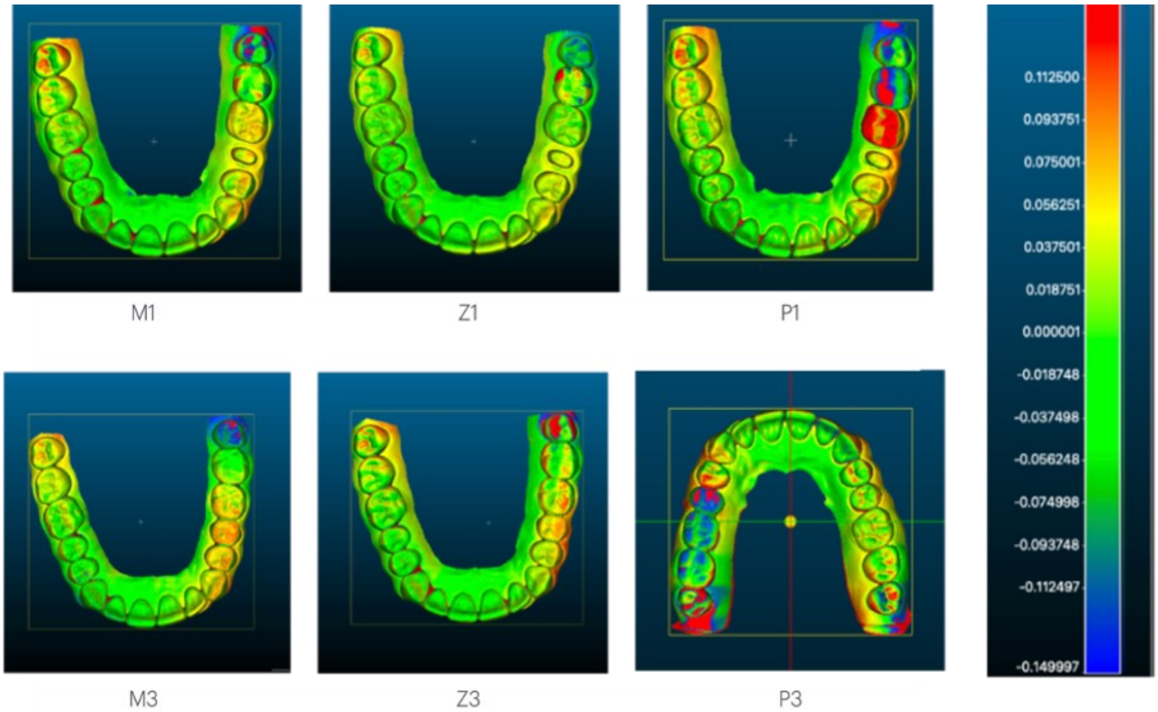

Figure 3: Color map obtained by overlaying STL data using reverse engineering software.
(M1: Metal crown, Z1: Zirconia crown, P1: Porcelain crown, M3: Metal fixed partial denture, Z3: Zirconia fixed partial denture, P3: Porcelain fixed partial denture. Red areas indicate negative deviations more than -150 µm, blue areas indicate positive deviations greater than 150 µm)

DISCUSSION

This study aimed to examine the effects of different restoration materials and restoration lengths on digital measurement accuracy. With the increasing use of digital impressions, it is conceivable that traditional model usage can be eliminated.[13] However, several studies have reported that digital impressions do not exhibit as high accuracy as traditional impression materials, such as polyvinyl siloxane (PVS), particularly in full-arch scans, although this difference is relatively small.[14] Based on the results of the study, the null hypothesis positing no significant difference between different material types and restoration lengths was rejected.

The primary objective was to determine whether the accuracy of a dust-free intraoral scanner is contingent on surfaces with distinct light reflection properties and whether it can adequately scan different materials. The M and Z groups underwent mechanical polishing, whereas the P group underwent a glazing process. The augmented deviation observed in the P group is attributed to the heightened light reflection associated with glazed porcelain.

The absence of a significant difference between the M and Z groups, despite uniform material colors in the P and Z groups (A2), suggests that the scanner accuracy is primarily contingent on the optical characteristics of the material surface rather than the restoration color.

Optical systems generate digital images by capturing light emitted from surfaces. However, light reflection and scattering from surrounding objects, particularly from shiny surfaces, can generate significant reflections. For instance, a porcelain crown proximate to adjacent teeth may prompt the scanner to detect reflected light, leading to inaccurate results (Figure 4). Moreover, the reduced exposure of restoration to light during intraoral scanning, compared with intraoral scanning within the mouth, may contribute to reflections on the surface of the P group during model scanning under ambient light conditions.

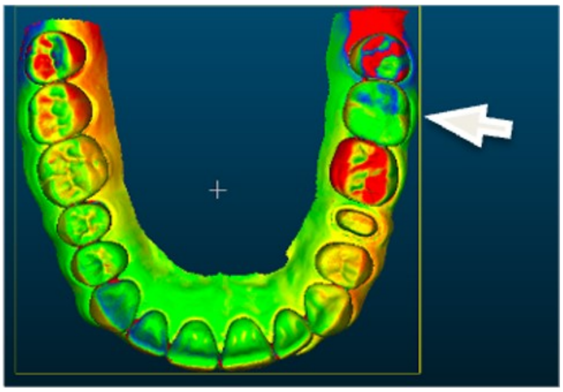

Figure 4: Effects of porcelain crowns on adjacent teeth.

The increased deviation observed in the porcelain crown group compared with the porcelain FPD group may be explained by the uneven application of powder used to reduce reflections during scanning with the reference scanner. This warrants further investigation in future studies.

Surface deviation, particularly distal to the arch and adjacent to the restoration, suggests that reflections from adjacent teeth, due to their optical properties, may exert a greater influence on adjacent tooth scans than the restoration itself. (Figure 3)

In a study by Kurz at all., it was proposed that keeping the scanner head perpendicular to the surface can reduce the reflections associated with restorations. However, maintaining the scanner head consistently perpendicular during surface scanning of teeth may not be feasible in practice.[15]

In another study conducted by Bocklet at all., the accuracy of dentin, amalgam, and composite materials was investigated using scans from a cadaver maxilla model. Similarly, reflections also occurred depending on the surface optical properties examined in this study.[5]

The following scanning, optical systems may encounter imaging errors during the image processing phase, potentially leading to misinterpretation of acquired data or modeling errors. The scanning method performed by Trios utilizing confocal microscopy with a light source may increase the susceptibility of surface optical properties. Future studies should explore different scanners utilizing various scanning methods with materials exhibiting diverse optical properties.[2]

One of the limitations of the study is its execution on a typodont model, which precludes the simulation of patient-related factors such as limited mouth opening, saliva, and blood. Additionally, typodont teeth lack properties comparable to those of natural tooth tissues. The repeated nearest point algorithm was preferred for overlaying scans, as in previous studies.[16,17] However, different superimposition algorithms are available, which could affect the results.[17]

CONCLUSION

Within the limitations of the study, the following conclusions were drawn:

The accuracy of the scanner can be affected by reflections coming from the restorations.

Deviations occurring in groups other than the porcelain group is within clinically acceptable limits.

Ethical Approval

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

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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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