Effect of substrate adjacent to the scan region on the trueness of four intraoral scanners: An in vitro study

Bahar Elter (baharelter@gmail.com)
Başkent University Hospital
Önjen Tak
Istinye University

Research Article

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Abstract

Objectives

The purpose of this in vitro study was to evaluate the trueness of four commercially available intraoral scanners on scanning different substrates that existed in the adjacent proximal contact area.

Materials and methods

Four intraoral scanners (Trios4, Trios3, Primescan, Omnicam) were used for scanning the intact enamel surface of a molar tooth, and six restorative materials (zirconia, lithium disilicate glass-ceramic, composite, hybrid ceramic, feldspathic ceramic, metal) that were located at the adjacent proximal contact area of the same tooth. Reference scans were obtained using an extraoral scanner (inEos X5). A 3-dimensional analyzing software (Geomagic Control X) was used to compare the reference and tested scans. The two-way analysis of variance (ANOVA) followed by Bonferroni correction was performed for statistical analyses ($\alpha = .05$).

Results

Trios3 and Trios4 showed higher trueness than Primescan, and Primescan had higher trueness than Omnicam ($p < 0.001$), while there were no differences between Trios3 and Trios4. Metal showed significantly higher Root Mean Square values (0.273 ± 0.24μm) than other substrates. No difference was found between the scanners' zirconia, lithium disilicate glass-ceramic, composite, and feldspathic ceramic scans ($p > .05$). For the metal, Trios3 and Trios4 showed higher trueness than Primescan and Omnicam, while Omnicam showed lower trueness among all scanners. For the hybrid ceramic, Trios3 showed higher trueness than Omnicam ($p < 0.001$). For the enamel, Trios3 showed higher trueness than Primescan and Omnicam ($p < 0.001$).

Conclusion

The trueness of intraoral scanners can be affected by the substrates that exist in the proximal contact area. Amongst all, the metal substrate affected most the trueness of the intraoral scanners.

Clinical Relevance:

The clinician should decide on the impression system, taking into account that the intraoral scanner and the surfaces to be scanned affect the trueness of the digital data. The deviation of the digital impression would be high in the presence of a metal restoration on the adjacent proximal surface.

INTRODUCTION

Intraoral scanners (IOSs) have become popular in clinical practice due to their benefits such as high precision impressions, eliminating the possible negative effects of conventional impression materials, saving time, and reducing the discomfort of the patient [1–3] Since computer-aided design and computer-aided manufacturing (CAD-CAM) technologies have been in use since the 1980s [4] in dentistry and developing every day according to the needs of the patients and the clinicians, IOSs too have been developing and becoming much more effective every day [3, 5, 6]. Also, the IOS companies have been developing their released scanners and software in order to provide more accurate images [7, 8]. There have been various IOSs in the dental market, and lots of studies comparing the trueness and precision of IOSs take place in literature [5, 8–11]. Trueness is related to conceiving the exact value of the measure, while precision is defined as the repeatability of the measure. The term accuracy refers to trueness and precision according to ISO 5725 [12]. These values have been measured and used in studies for analyzing the scanning ability of an IOS and comparing the different systems among themselves [8–10, 13, 14].

There have been different imaging technologies that are used by the intraoral scanning systems as active triangulation, confocal laser scanning, active wave-front sampling, and stereophotogrammetry. Likewise, image capturing systems may differ as capturing and stitching the image and video sequence principle [15–17]. Additionally, the latest version of CEREC IOS (Primescan) was released with a new scanning technology as high-frequency contrast analysis and dynamic depth scan [18, 19].

Generally, an IOS projects light onto the area that is scanned, and the reflected light is read back by the sensor of the camera [3, 15].Therefore, the optical properties of the scanned area are important as light reflection will be affected [5, 9, 10, 14, 20].The amount of reflected light that is read by the sensor may differ with the translucency, reflectivity, and refraction index of the scanned tissue/material, affecting the quality of the captured data. When various dental restorative materials and intraoral tissues are taken into consideration, different light reflections from the scanned area can affect the accuracy of the impression [9, 10, 14]. Therefore, the accuracy of the impression of the areas adjacent to the relevant restoration area may become important as that may affect the contact precision. Adjusting the contacts is a task that requires precision while designing [21] and would be affected by the trueness of the data, which would end up with loose or tight contact areas if the deviation is high.

When it comes to the imaging technologies of the extraoral scanners (EOSs), they have been divided as structured light, laser, and contact scanners [11, 22]. Non-contact scanners (structured light and laser) can use white or blue light. Blue light technology was developed recently to decrease the impression errors and exhibit greater scanning repeatability [23]. Recently, several studies have used extraoral scanners as reference scanners [13, 24, 25] as they exhibit high trueness [26].

The aim of this in vitro study was to evaluate and compare the scanning trueness of four different intraoral scanners (Cerec Omnicam, Cerec Primescan, 3Shape Trios 3, 3Shape Trios 4) and six different restorative materials that are likely to be located at the proximal contact area.

The null hypotheses was that IOS and adjacent substrate would not affect the trueness of the scans.

MATERIALS AND METHOD

In this in vitro study, clinical conditions were imitated by using extracted human teeth and a phantom head while performing the scans. For the usage of caries-free, extracted maxillary right first and second premolar teeth, approval was received by the Istanbul Okan University Non-Interventional Clinical Research Ethics Committee (130-23.12.20). The mesial proximal surface of the maxillary right first molar tooth, which was considered to be relatively harder to scan, was chosen as the study area for scanning trueness evaluation. The extracted tooth sizes were chosen to be similar to the teeth found in the experimental model jaw. Freshly extracted maxillary right first molar and second premolar teeth roots were cleaned from soft tissue residues with a scaler and stored in 0.1% thymol solution for a week. For the second premolar, a full crown preparation with 2.0 mm occlusal reduction, 1.0 mm chamfer finish line, and ~ 10 degrees convergence angle were handled as it was considered as the tooth to be restored. After cutting approximately half of the roots for easy positioning, the prepared premolar and intact molar teeth were embedded in the upper model jaw (ANA-4V, Frasaco) at the empty places of the maxillary right second premolar and first molar with the aid of a pink laboratory silicone (Silaform 85K, Siladent, Böhme & Schöps). The upper and lower model jaws were adapted to a phantom head (PK-1, Frasaco). The position of the head was adjusted as if it were the position of the patient's head in the dental unit. The digital impressions from the first premolar to the second molar teeth, including the prepared second premolar and adjacent first molar teeth, were taken with four different IOSs as CEREC Omnicam (CEREC SW5; Dentsply Sirona) CEREC Primescan (CEREC SW5; Dentsply Sirona), Trios 3 (3Shape A/S and Trios 4 (3Shape A/S). The scans were made by the same experienced operator (B.E.) ten times each following the manufacturers' scanning strategies. The scanning time of each was standardized by the operator to be between 25–35 seconds. The reference scanner was a laboratory (extraoral) scanner (inEos X5, Dentsply, Sirona), and the reference model scans were captured with this extraoral scanner (EOS). After the intact tooth reference scans, including the prepared second premolar and intact first molar teeth scans, a mesio-occlusal restoration cavity was prepared on the mesial half of the molar tooth between the mesio-buccal and mesio-palatal cusps with a tapered flat end medium grit diamond bur. The pulpal floor depth of the cavity was 3–3,5 mm, and the tapers of the cavity walls were ~10°-12. The proximal portion of the cavity was finished 2 mm coronal to the cemento-enamel junction.

The cavity was scanned with an EOS (inEos X5, Dentsply, Sirona), and a restoration was designed. According to the design, a zirconia restoration was milled from a CAD-CAM blank (Cercon ht A1, Dentsply, Sirona), and the sintering was completed with a dental furnace (Cerec SpeedFire, Dentsply, Sirona). A lithium disilicate glass-ceramic restoration was milled from a CAD-CAM block (IPS e.max A1, Ivoclar Vivadent) and crystallized in a ceramic furnace (Vita Vacumat 6000 M, Vita Zahnfabrik). The feldspathic ceramic restoration was milled from a CAD-CAM block (CEREC Block A1, Dentsply, Sirona). The outer surfaces of the three restorations were glazed with a universal glaze material (Celtra Universal Overglaze, Dentsply Sirona) according to the manufacturer's instructions. The hybrid ceramic restoration was milled from a CAD-CAM block (Cerasmart A1, GC), and the outer surface was glazed with a light-cured glaze

material (Optiglaze, GC). The composite restoration was milled from a CAD-CAM block that was prepared manually by filling the prepared silicone mold with a size of C14 block[27] (Fig. 1). A posterior composite resin material (Clearfil Majesty Posterior, Kuraray Noritake) was used and filled in layers of 1mm and light cured. A CEREC adapter was luted on the prepared composite block for adapting the milling device. After the milling, the outer surface was hand polished with one-step polishing rubber burs (OptraPol, Ivoclar Vivadent). All previously mentioned restorations were milled with a laboratory milling machine (inLab MC X5, Dentsply Sirona). For the metal group, the same standard tessellation language (STL) file was used for manufacturing the restoration from Co-Cr alloy with a laser-sinter machine (SISMA MYSINT100) and hand polished with metal polishing burs (Metal polishing kit, Shofu) after the sintering process. The manufactured restorations are shown in Fig. 2.

The restorations were adapted to the restoration cavity (Fig. 3A) with a glycerin gel (SR Gel, Ivoclar Vivadent) one by one and scanned with the IOSs (Fig. 3B) and an EOS following the same procedures as the first scanned groups. All scans were done after calibrations and according to the manufacturer's instructions. The datasets of each scan were saved as STL files and imported to three-dimensional analyzing software (Geomagic Control X, 3D Systems). By using the software, the reference models were trimmed and split, leaving only the mesial proximal areas so that deviations in other regions were not included in the calculation. The EOS and IOSs data were imported as reference data and measured data, respectively, and both data were superimposed. Initial alignment, best fit alignment, and 3D compare steps were followed. The root mean square (RMS) values which are used as the indicant for trueness evaluation, were calculated according to the deviations between reference and measured data. Higher RMS values indicate lower trueness. The deviations were also shown with 13 colored map. The positive deviation was specified by red-yellow, and the negative deviation was by blue-turquoise color. (Fig. 4)

A priori power analysis was performed by using a software program (G*Power 3.1.9.4). The minimum sample size was determined as 3 (effect size: 1.75, power: 0.95). In the present study, 10 impressions for each group were taken to increase the power of the study. A software program (IBM SPSS Statistics 22) was used for the statistical evaluation of the data. A two-way analysis of variance (ANOVA) was performed to examine the significance of both scanner and material effects on the accuracy of impression. Bonferroni method was used for adjustments in multiple comparisons. The statistical significance level was set at 0.05.

RESULTS

Two-way ANOVA tests showed significant differences in trueness for different materials ($p < 0.001$) and scanners ($p < 0.001$). The RMS values (mean ± SD) of the materials scanned with each scanner are presented in Table 1. According to the results of the pairwise comparisons of the scanners, there were significant differences between all scanners except for Trios 3 and Trios 4 ($p = 1.00$) (Table 2).

Table 1
RMS values (mean ± SD) of the materials obtained by the intraoral scanners.

Scanner	Material	N	Mean ± SD
Primescan	Zirconia	10	0.03 ± 0.01
	Metal	10	0.41 ± 0.09
	Lithium disilicate glass-ceramic	10	0.04 ± 0.01
	Composite	10	0.02 ± 0.00
	Feldspathic Ceramic	10	0.02 ± 0.00
	Hybrid Ceramic	10	0.04 ± 0.00
	Enamel	10	0.07 ± 0.00
	Total	70	0.09 ± 0.14
Omnicam	Zirconia	10	0.02 ± 0.01
	Metal	10	0.52 ± 0.10
	Lithium disilicate glass-ceramic	10	0.03 ± 0.01
	Composite	10	0.03 ± 0.01
	Feldspathic Ceramic	10	0.02 ± 0.00
	Hybrid Ceramic	10	0.08 ± 0.12
	Enamel	10	0.07 ± 0.00
	Total	70	0.11 ± 0.18
Trios 4	Zirconia	10	0.02 ± 0.02
	Metal	10	0.10 ± 0.02
	Lithium disilicate glass-ceramic	10	0.02 ± 0.01
	Composite	10	0.02 ± 0.00
	Feldspathic Ceramic	10	0.01 ± 0.00
	Hybrid Ceramic	10	0.04 ± 0.01
	Enamel	10	0.03 ± 0.00
	Total	70	0.04 ± 0.03
Trios 3	Zirconia	10	0.02 ± 0.01
	Metal	10	0.07 ± 0.02

Scanner	Material	N	Mean ± SD
	Lithium disilicate glass-ceramic	10	0.03 ± 0.01
	Composite	10	0.02 ± 0.00
	Feldspathic Ceramic	10	0.02 ± 0.01
	Hybrid Ceramic	10	0.04 ± 0.00
	Enamel	10	0.02 ± 0.00
	Total	70	0.03 ± 0.02
Total	Zirconia	40	0.02 ± 0.01
	Metal	40	0.27 ± 0.21
	Lithium disilicate glass-ceramic	40	0.03 ± 0.01
	Composite	40	0.02 ± 0.01
	Feldspathic Ceramic	40	0.02 ± 0.01
	Hybrid Ceramic	40	0.05 ± 0.05
	Enamel	40	0.05 ± 0.02
	Total	280	0.07 ± 0.12

Table 2
Pairwise comparisons of the intraoral scanners.

Scanner	N	Mean ± SD	Median	Maximum	Minimum	P < .001
Primescan	70	0.09 ± 0.13^{a}	0.04	0.57	0.01	
Omnicam	70	0.11 ± 0.18^{b}	0.03	0.71	0.01	
Trios 4	70	0.04 ± 0.03^{c}	0.03	0.14	0.01	
Trios 3	70	0.03 ± 0.02^{c}	0.02	0.09	0.01	
Different superscript letters indicate a significant difference (P < .001)						

Trios 3 showed higher trueness values than Primescan (p = 0.061) and Omnicam (p = 0.08); Trios 4 showed higher trueness values than Primescan (p = 0.054) and Omnicam (p = 0.073); Primescan had higher trueness values than Omnicam (p = 0.019).

Pairwise comparisons of the materials are given in Table 3. The metal surface showed significantly higher RMS values (0.273 ± 0.24µm) therefore having lower trueness than all other restorative materials.

Table 3
Pairwise comparisons of the RMS values of the tested materials.

(I) Material	(J) Material	Mean Difference (I-J)
Zirconia	Metal	− .250*
	Lithium disilicate glass-ceramic	− .006
	Composite	.002
	Feldspathic Ceramic	.005
	Hybrid Ceramic	− .027*
	Enamel	− .024*
Metal	Zirconia	.250*
	Lithium disilicate glass-ceramic	.244*
	Composite	.252*
	Feldspathic Ceramic	.255*
	Hybrid Ceramic	.223*
	Enamel	.226*
Lithium disilicate glass-ceramic	Zirconia	.006
	Metal	− .244*
	Composite	.008
	Feldspathic Ceramic	.012
	Hybrid Ceramic	− .021
	Enamel	− .018
Composite	Zirconia	− .002
	Metal	− .252*
	Lithium disilicate glass-ceramic	− .008
	Feldspathic Ceramic	.004
	Hybrid Ceramic	− .029*
	Enamel	− .026*

(I) Material	(J) Material	Mean Difference (I-J)
Feldspathic Ceramic	Zirconia	− .005
	Metal	− .255*
	Lithium disilicate glass-ceramic	− .012
	Composite	− .004
	Hybrid Ceramic	− .032*
	Enamel	− .030*
Hybrid Ceramic	Zirconia	.027*
	Metal	− .223*
	Lithium disilicate glass-ceramic	.021
	Composite	.029*
	Feldspathic Ceramic	.032*
	Enamel	.003
Enamel	Zirconia	.024*
	Metal	− .226*
	Lithium disilicate glass-ceramic	.018
	Composite	.026*
	Feldspathic Ceramic	.030*
	Hybrid Ceramic	− .003

When analyzing the scanning trueness of zirconia, lithium disilicate glass-ceramic, composite, and feldspathic ceramic surfaces, no significant difference was found between the scanners ($p > .05$).

Trios 3 (0.065 ± 0.02 µm) and Trios 4 (0.1 ± 0.02 µm) showed higher trueness values than Primescan (0.41 ± 0.09 µm) and Omnicam (0.518 ± 0.09 µm) for the metal surface scans, while Omnicam showed lower trueness values among all scanners. For the hybrid ceramic surface, Trios 3 showed higher trueness than Omnicam ($p = 0.042$), while other scanners showed similar results ($p > 0.001$). For the enamel surface, Trios 3 showed significantly higher trueness than Primescan ($p = 0.05$) and Omnicam ($p = 0.045$), while there were no differences among other scanners ($p > 0.001$). Figure 5 shows the deviation values of each material depending on the scanners.

DISCUSSION

According to the results of the present study, the null hypotheses was rejected because the trueness of the scanned data was affected by the adjacent substrate and the intraoral scanner.

A phantom head was used in the present study to simulate intraoral conditions. Similarly, several studies used phantom heads instead of hand-scanning the models [28, 29]. In a study, it was reported that intraoral scanning of the dental arc was less precise than scanning the same arc model extraoral [6]. However, different from the present study, another intraoral scanner (itero, Align Technologies) and an extraoral scanner (D250, 3shape) were used for comparisons. Limited space for the movement of the intraoral scanner head according to interocclusal space height, buccal tissues, and tongue may affect the scanning time and efficiency; therefore, it becomes important to simulate the intraoral conditions as possible. Also, higher deviation values were reported at posterior regions [6, 30], which means the scanning region is important due to the effect of the same mentioned factors. In the present study, the proximal surface of a maxillary first molar tooth, which was considered to be relatively difficult to scan, was selected.

There have been studies investigating the scanning accuracies of different substrates. It was reported that the optical properties of scanned substrates affected the trueness of the intraoral scanners [5, 9, 10, 14] In the present study, different restorative materials such as zirconia, metal, lithium disilicate glass-ceramic, feldspathic ceramic, hybrid ceramic, composite for posterior, and natural tooth enamel surface were included for substrate scans. The optical properties of different substrates become important, especially when the contact is going to be established with those surfaces. In the present study, the mesial contact surface of the maxillary right molar tooth was changed according to the restorative material variance. According to the results, the metal surface showed the highest RMS values, which means lower trueness. This result supports the result of the other studies [5, 10, 14]. Metal surfaces that reflect greater light can cause reflected light to be processed incorrectly or for a longer time. Therefore, metal surface scanning shows higher deviations [31]. Studies reported that also enamel surfaces showed lower accuracy levels than dentin, which was reported to be due to translucency [9, 10]. In the present study, the trueness of the natural enamel surface was higher than the metal surface; however, the trueness of zirconia, composite and feldspathic ceramic surfaces were higher than the enamel surface. The result was as expected because the translucency of enamel was higher than zirconia and posterior composite material. However, feldspathic ceramic, which has enamel-like properties, showed higher trueness than enamel. It may be due to the overall thickness of the restoration that might decrease the translucency. Also, natural teeth have other optical properties, such as opalescence and fluorescence [32] that may affect the scanning trueness.

The composite surface showed higher trueness than metal, hybrid, and enamel surfaces, and there were no differences between composite and the other materials. The high scanning trueness of composite surface may be due to low light transmittance [9, 10] and also due to mechanical polishing that may contribute to light reflection that is more suitable for data capturing of the IOSs [20]. All ceramic-

containing materials were over glazed, resulting in a glossy surface which may lead to excessive light reflection complicating the scanning process. However, although zirconia surface was over-glazed like other ceramic-containing materials, it showed high trueness, which is thought to be due to low light transmittance due to the high refractive index of the material [33, 34]. The scanning trueness of zirconia showed similar results with the composite surface; thus, it showed higher trueness than metal, hybrid, and enamel, and no difference was observed with the other materials. For the lithium disilicate glass-ceramic surface, there were no significant differences between any other materials except for the metal surface. That may be due to the low translucency (LT) feature of the ceramic that may lead to a translucency degree which made the scans insignificantly different from the other substrates. Another study used medium translucency lithium disilicate glass-ceramic and reported lower trueness when compared to polished amalgam and composite surface for the Primescan scans however reported no differences between substrates for the Trios 3 scans [9].

When IOS were evaluated separately, there was no statistically significant difference between Trios 3 and Trios 4, and they both showed higher trueness than Omnicam and Primescan regardless of the substrates. Omnicam showed the lowest trueness values compared to all other IOSs. It may be important to emphasize that when comparisons were handled according to each material separately, there were no differences between IOSs' scanning trueness of zirconia, lithium disilicate glass-ceramic, composite and feldspathic ceramic. The scanning trueness of metal and enamel surfaces was higher for Trios 3 and Trios 4. For both surfaces, Omnicam showed the lowest trueness than Primescan, and Primescan showed lower trueness than both Trios scanners.

Dutton et al. [9] reported for all substrates (enamel, gold, zirconia, amalgam (polished and unpolished), lithium disilicate, five different composites, white core, blue core, dentin) that Primescan had higher trueness than Omnicam and Trios 3. Also, it was reported that the translucency of the tested materials affected the trueness and precision negatively. In another study, the substrates were prepared as enamel, dentin, core composites, restorative composites, alloys, and all-ceramic materials such as zirconia and lithium disilicate glass-ceramic and located in a mandibular typodont model. No difference was reported between Primescan and Trios 3, while Omnicam showed lower trueness [7]. Different from both studies, in the present study, Trios 3 showed higher trueness than Primescan. Substrate differences or scanning ambiance differences may have contributed to the dissimilar results.

In the present study, clinical conditions were tried to be simulated; however, there were limitations as there were no patient-related factors like head or tongue movements, saliva contamination, breath that mist the IOS head, etc. Four IOSs from two companies were tested in the present study; further studies are needed for testing other commercially available IOS systems and also for testing other dental materials with different color and translucency levels that may affect the contact surfaces of the planned restorations.

CONCLUSIONS

Within the limitations of the present study, it can be concluded that the substrates that can be found adjacent to the prepared tooth may affect the trueness of the digital impression, therefore, the contact strength of the upcoming restoration. Amongst all tested materials, the metal surface affected most of the trueness of all IOS systems. Omnicam, followed by Primescan, was more affected by the metal surface. In clinical practice, if there is a metal surface in the scanning area adjacent to the prepared teeth, the impression system to be used may be selected accordingly.

Declarations

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The authors report no conflicts of interest related to the present study.

Author contributions

Bahar Elter, contributed to methodology, investigation and writing the manuscript; Önjen Tak, contributed to methodology, data analysis and revised the manuscript. All authors revised and approved the final manuscript for submission.

Ethics statement

Ethics approval was received by the Istanbul Okan University Non-Interventional Clinical Research Ethics Committee (130-23.12.20).

Consent to participate

For the usage of extracted human teeth, the individual with teeth extractions due to periodontal disease was informed about the study, and signed consent was obtained.

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Conflict of Interests

The authors Bahar Elter and Önjen Tak declare no conflict of interest regarding this work.

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Figures

Figure 1

The silicone mold prepared for manufacturing a composite block with a size of C14, manufactured block by filling the mold and the CEREC adaptor to be luted to the block.

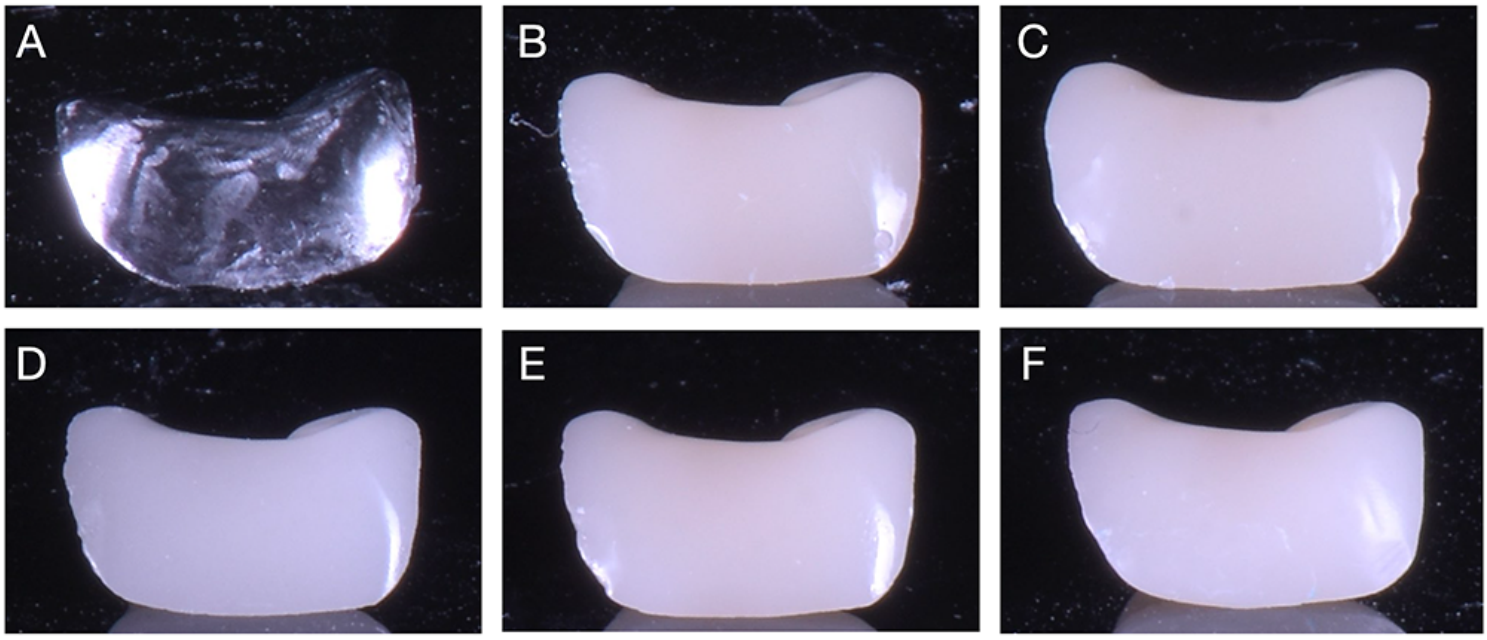

Figure 2

Manufactured restorations. A, Metal. B, Hybrid ceramic. C, Zirconia. D, Feldspathic ceramic. E, Lithium disilicate glass-ceramic. F, Composite.

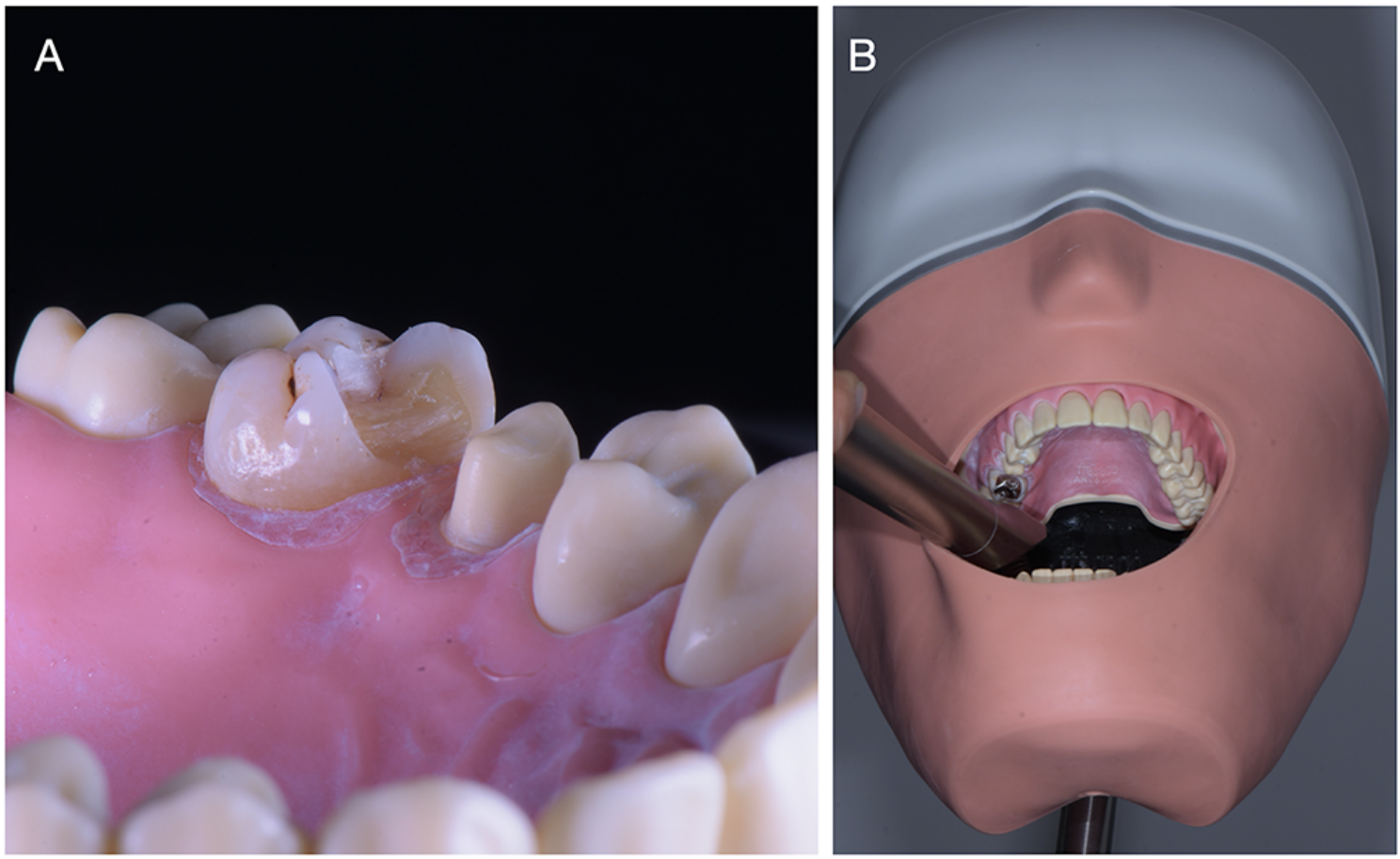

Figure 3

A, Positioned molar tooth with the restoration cavity and the premolar tooth with a crown preparation on typodont model. B, Representative image for the scanning procedure on the phantom head.

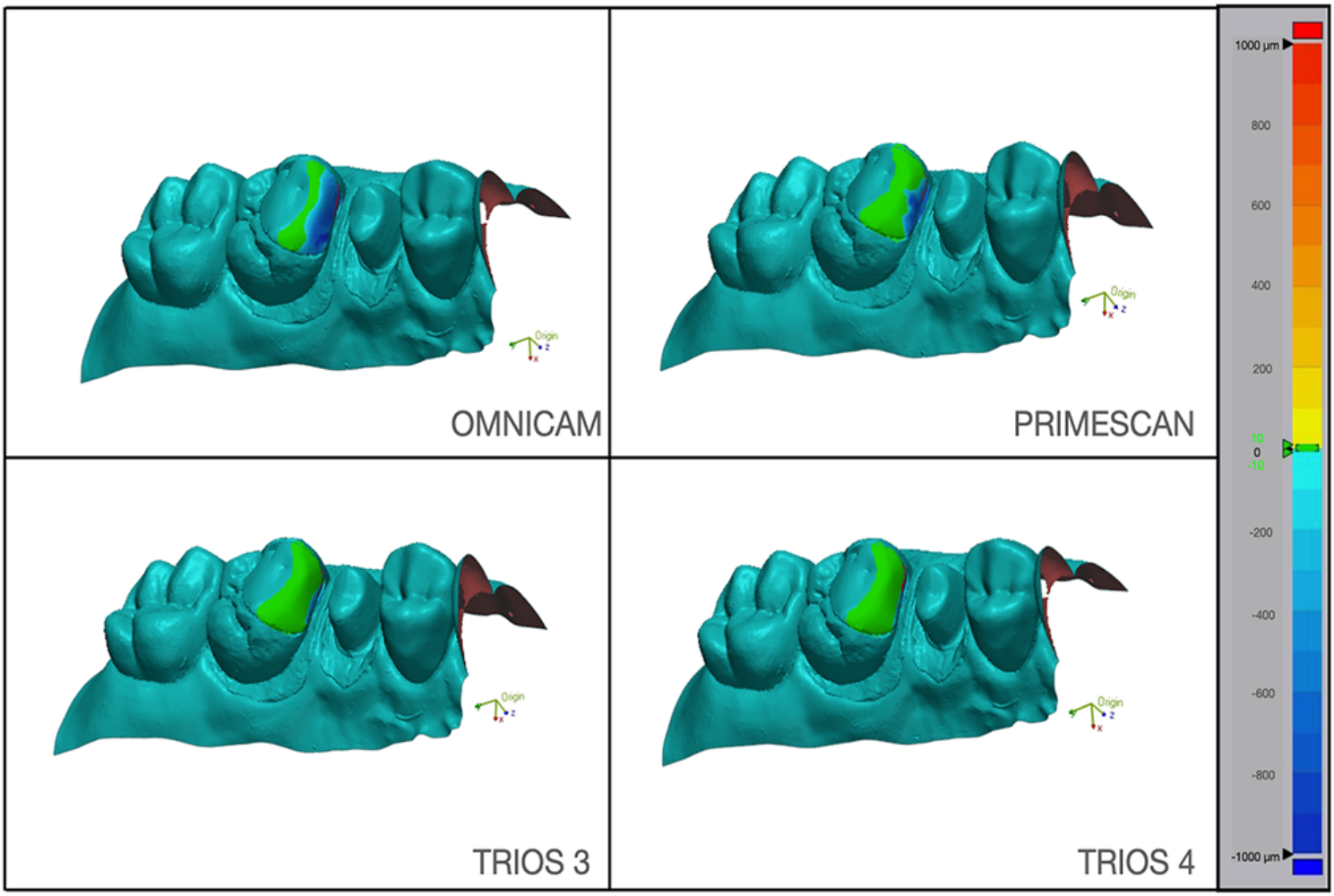

Figure 4

Representative images from color maps of the metal restoration scanned with different intraoral scanners. Blue shows the negative deviation of the reference, and green shows the deviation within the range of nominal values. A, Cerec Omnicam. B, Cerec Primescan. C, 3Shape Trios 3. D, 3Shape Trios 4.

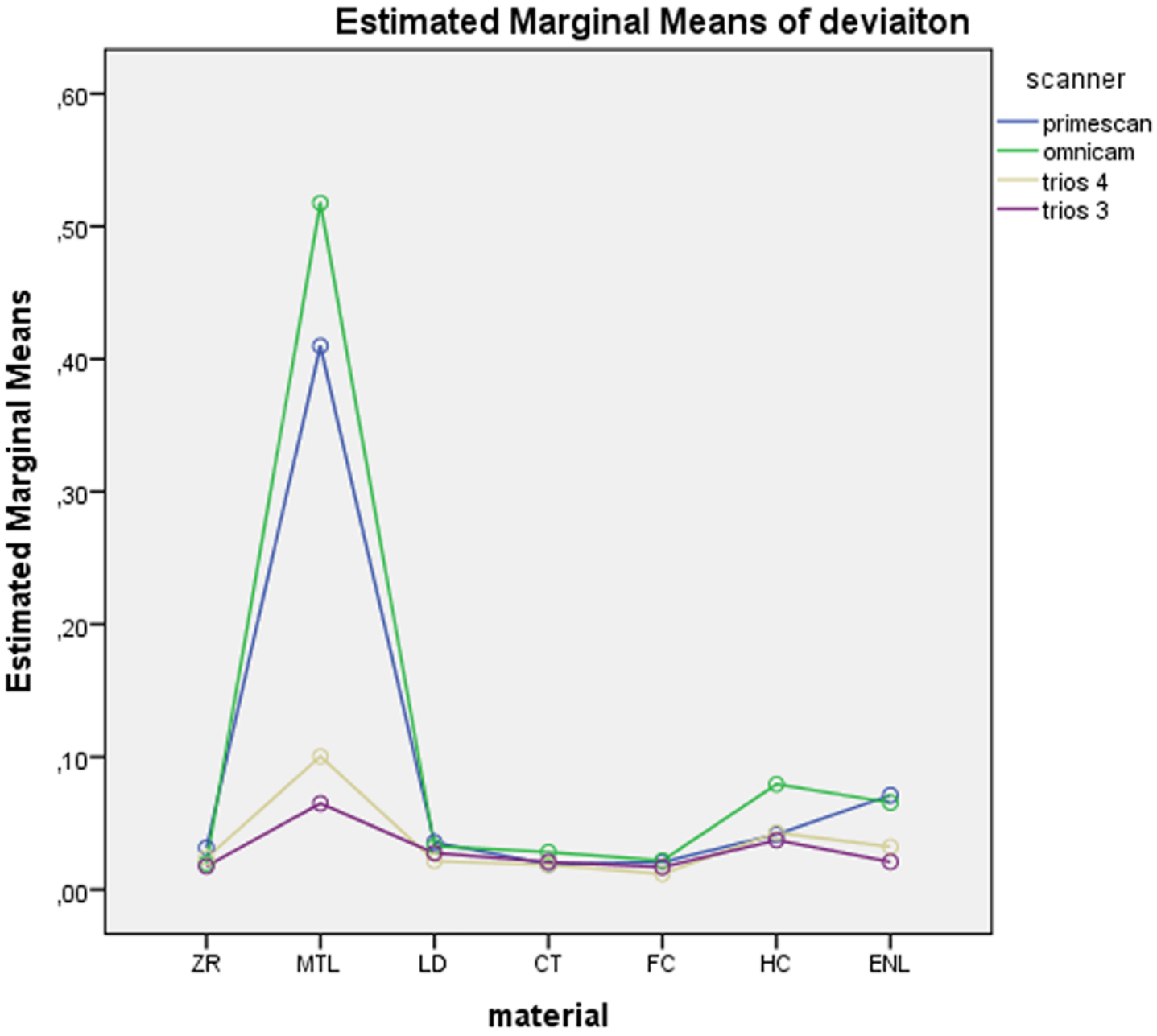

Figure 5

The trueness of intraoral scanners according to the tested materials.

(ZR, zirconia; MTL, metal; LD, lithium disilicate glass-ceramic; CT, composite; FC, feldspathic ceramic; HC, hybrid ceramic; ENL, enamel.)