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Trueness of intraoral scanners in digitizing specific locations at the margin and intaglio surfaces of intracoronary preparations

Jin-Young Kim, Ryan ; Benic, Goran I ; Park, Ji-Man

Abstract: STATEMENT OF PROBLEM Studies evaluating the trueness of intraoral scanners (IOSs) at anatomic locations within an intracoronary preparation are lacking. **PURPOSE** The purpose of this in vitro study was to evaluate the trueness of digital scans obtained by IOSs at the margin and intaglio surfaces of intracoronary preparations. **MATERIAL AND METHODS** Six IOSs (CEREC Omnicam, E4D, FastScan, iTero, TRIOS, Zfx IntraScan) were used to obtain digital scans of various intracoronary preparations. Standard tessellation language (STL) data sets obtained from a reference scanner and each IOS were superimposed, and the deviation of the digital casts was assessed at multiple measuring points along the margin and intaglio surfaces of each preparation. The Kruskal-Wallis test and multiple Mann-Whitney tests were used to detect differences in trueness ($=.05$). **RESULTS** The overall median trueness values were lowest for TRIOS (23.9 μ m), followed by Zfx IntraScan (24.6 μ m), iTero (25.4 μ m), FastScan (26.1 μ m), CEREC Omnicam (26.9 μ m), and E4D (77.5 μ m). The greatest deviation was generally observed at the line angles between the preparation surfaces. The axiangular line angle was the most error-prone location in the cavity preparations. An increased tendency to produce a more accurate impression was observed when the cavity had a greater width and more divergent walls. **CONCLUSIONS** The trueness of digital scans was influenced by the type of IOS and the location within a prepared cavity. The trueness decreased at the line angles between the preparation surfaces, particularly at the axiangular line angle. Among the tested IOSs, E4D produced the least accurate digital scans.

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Trueness of intraoral scanners in digitizing specific locations at the margin and intaglio surfaces of intracoronal preparations

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RESEARCH AND EDUCATION

Trueness of intraoral scanners in digitizing specific locations at the margin and intaglio surfaces of intracoronal preparations

ABSTRACT

Statement of problem. Studies evaluating the trueness of intraoral scanners (IOSs) at anatomic locations within an intracoronal preparation are lacking.

Purpose. The purpose of this in vitro study was to evaluate the trueness of digital scans obtained by IOSs at the margin and intaglio surfaces of intracoronal preparations.

Material and methods. Six IOSs (CEREC Omnicam, E4D, FastScan, iTero, TRIOS, Zfx IntraScan) were used to obtain digital scans of various intracoronal preparations. Standard tessellation language (STL) datasets obtained from a reference scanner and each IOS were superimposed, and the deviation of the digital casts was assessed at multiple measuring points along the margin and intaglio surfaces of each preparation. The Kruskal–Wallis test and multiple Mann–Whitney tests were used to detect differences in trueness ($\alpha=.05$).

Results. The overall median trueness values were lowest for TRIOS (23.9 μm), followed by Zfx IntraScan (24.6 μm), iTero (25.4 μm), FastScan (26.1 μm), CEREC Omnicam (26.9 μm), and E4D (77.5 μm). The greatest deviation was generally observed at the line angles between the preparation surfaces. The axiogingival line angle was the most error-prone location in the cavity preparations. An increased tendency to produce a more accurate impression was observed when the cavity had a greater width and more divergent walls.

Conclusions. The trueness of digital scans was influenced by the type of IOS and the location within a prepared cavity. The trueness decreased at the line angles between the preparation surfaces, particularly at the axiokingival line angle. Among the tested IOSs, E4D produced the least accurate digital scans.

CLINICAL IMPLICATIONS

There are significant differences in the trueness of digital scans obtained by different IOSs. The most difficult areas in which to obtain accurate digital scans by all IOSs were the line angles where 2 surfaces met, particularly at the axiokingival line angle.

INTRODUCTION

Traditional treatment procedures are evolving through the use of digital technologies, including computer-aided design and computer-aided manufacturing (CAD-CAM).^{1,2} Different CAD-CAM systems are available for clinical use, revolutionizing the processes involved in delivering various types of restorations.³⁻⁷

Trueness is the term used to describe the accuracy of a measurement method and is defined as the closeness of agreement between test results and a reference value.⁸ Industrial scanners such as Alicona Infinite Focus (Alicona Imaging) and Sensable S3 (Solutionix) have been used to obtain reference data of experimental models for determining the trueness of intraoral scan data.⁹⁻¹¹ The trueness of CAD-CAM restorations has been evaluated by comparing the trueness of restorations fabricated from digital scans and conventional impressions in terms of internal and/or marginal discrepancies.¹²⁻¹⁵ These investigations have reported that

restorations made from digital scans acquired by intraoral scanners (IOSs) present similar or better accuracy than those made from conventional impressions.

The accuracy of a CAD-CAM fabricated restoration is affected by different factors, because accumulated errors throughout the entire digital workflow affect the definitive outcome, hindering the evaluation of the performance of the IOS itself. Digitizing of the intraoral situation is the first step in which errors may be introduced even before the designing and manufacturing processes. Because the marginal and internal adaptation of restorations is considered a predictive factor for clinical success,¹⁶⁻¹⁸ the accuracy of an IOS plays a crucial role in ensuring that the restoration has a satisfactory outcome.

Although studies have evaluated the accuracy of IOSs in obtaining scans of single teeth,¹⁹⁻²¹ multiple units,²²⁻²⁴ and complete-arches,^{2,24-29} information is lacking on the accuracy of IOSs for digitally scanning intracoronal preparations. Therefore, in a preliminary study,¹⁰ the trueness and precision of 6 IOSs regarding the digital scans of various intracoronal preparations were examined. The results confirmed that different IOSs and types of cavity design influenced the accuracy of the digital scans. Although a general trend of deviation and errors in the digital casts obtained using IOSs was found in the previous study, reports on the trueness of IOSs at specific locations of interest within a cavity prepared for intracoronal restoration are lacking.

Therefore, the purpose of the present investigation was to investigate the difference in the trueness of digital scans acquired by the IOSs at multiple locations along the margin and intaglio surfaces of various intracoronal preparations. The null hypothesis was that no differences would exist between a digitized IOS cast and a reference cast, regardless of the type of IOS type or cavity location.

MATERIAL AND METHODS

Commercially available epoxy resin typodont teeth prepared for inlay restorations (A50H-Set; Nissin Dental Products Inc) set in maxillary and mandibular jaws (E50-500A; Nissin Dental Products Inc.) served as the master model. Within the arches, 5 posterior teeth were selected for evaluation (Fig. 1): a maxillary first premolar with an occlusal preparation; maxillary first and second molars with a mesio-occlusal preparation; a mandibular first premolar with a mesio-occluso-distal and a lingual cusp reduction preparation; and a mandibular first molar with a bucco-occlusal preparation. Each tooth presented an intracoronal cavity preparation in the occlusal area with or without proximal extension and with or without cusp reduction. An occlusal cavity was present in every tooth, and a box cavity preparation was present in the mesial interproximal aspect of the maxillary first and second molars, in the mesial and distal interproximal aspects of the mandibular second premolar, and in the buccal aspect of the mandibular first molar. Cusp reduction was made only at the lingual cusp of the mandibular second premolar.

Digital scans of the master model were made by using a reference scanner (Sensable S3; Solutionix) and 6 IOSs: CEREC Omnicam (Dentsply Sirona); E4D (D4D Technologies); FastScan (IOS Technologies); iTero (Cadent); TRIOS (3Shape A/S), and Zfx IntraScan (Zfx GmbH) (Table 1). The cast was coated with a thin layer of scanning powder before scanning with the FastScan. The reference scanner had an accuracy of 10 micrometers and a resolution of 1.4 megapixels. The scanning procedure was repeated, according to the manufacturers' instructions, 5 times for each IOS, and data were stored in standard tessellation language (STL) format. No external force was applied to the master model during the entire scanning procedure. All experiments were conducted at 23 ± 2 °C and $50 \pm 5\%$ relative humidity.

A reverse engineering program (Rapidform; INUS Technology Inc) was used for image superimposition and evaluation. Digital casts of each tooth were extracted, and the STL datasets from the reference scanner and each IOS were superimposed by using a best-fit algorithm. For trueness evaluation, the deviation of the digital casts obtained by the IOSs from the reference cast was measured at the margin and intaglio surfaces of each preparation. Figure 2 shows the specific measuring points for comparative evaluation: 4 measuring points in the occlusal cavity preparation including the cavosurface margin, external wall, pulpal line angle, and pulpal floor; 7 measuring points in the box cavity preparation including the cavosurface margin, gingival floor, axiogingival line angle, axial wall, axiopulpal line angle, box wall, and box line angle; and 2 measuring points in the cusp capping area including cusp reduction and counter bevel. To elucidate the effect of the variation of cavity access for scanning on the trueness of the IOSs, the mesio-occlusal cavity preparations on the maxillary first and second molars, the latter with greater cavity width, more divergent walls and sharper line angles were also compared.

Statistical analyses were conducted by using a software program (IBM SPSS Statistics, v20; IBM Corp) ($\alpha=.05$). The Kolmogorov–Smirnov test determined that the data were not normally distributed. Therefore, the median trueness values of the IOSs were analyzed by using the Kruskal–Wallis test, followed by multiple Mann–Whitney tests for pairwise comparisons between groups.

RESULTS

The trueness of the IOSs varied among the types of cavity preparation and among the measuring points in each cavity preparation (Table 2). The TRIOS scanner showed the lowest overall

median trueness values (23.9 μm), followed by Zfx IntraScan, iTero, FastScan, and CEREC Omnicam. E4D had the highest overall median trueness value (77.5 μm) (Table 2).

When the trueness values of all IOSs were pooled together for each measuring point, the overall values ranged from 5.3 to 65.6 μm . Irrespective of the type of tooth and cavity preparation, greater deviation was observed at the line angles between the preparation surfaces. Among the measuring points within the prepared occlusal cavity, the lowest overall trueness values were observed at the external wall (17.2 μm), and the highest values were observed at the pulpal line angle (39.8 μm). Within the prepared box cavity, the box wall had the lowest overall trueness values (18.9 μm), whereas the axiokingival line angle had the highest values (65.6 μm). The trueness values of all IOSs were smallest at the cusp capping area of the mandibular second premolar, particularly at the cusp reduction (5.3 μm) (Table 3).

Figure 3 presents the pattern and the magnitude of deviations of the 6 IOSs at the margin and intaglio surfaces of each intracoronary preparation. When the 2 mesio-occlusal cavity preparations in the maxillary first and second molars were compared, the maxillary first molar exhibited considerably greater deviations for all measuring points and for all IOSs.

DISCUSSION

The trueness of IOSs on the entire surface of the tooth or teeth being scanned has been evaluated.¹⁹⁻²⁹ However specific locations within a prepared cavity were not analyzed. The present study was conducted to analyze the trueness of IOSs in obtaining digital scans of inlay cavity preparations and to provide information on the trueness values at multiple measuring points along the margin and intaglio surfaces of intracoronary preparations, which, to the authors' knowledge, has not previously been reported in the literature. The findings of the present study

do not support the null hypothesis that the type of IOS and measuring points in the inlay cavities would not affect the trueness of IOSs because these values varied considerably among both the measuring points and the IOSs.

In the present study, artificial teeth with various intracoronal preparation designs served as the master model from which digital scans were obtained for comparison. Although both the maxillary first and second molars had similar mesio-occlusal cavity preparations with an occlusal cavity extending to a mesial proximal box cavity, they differed in the depth and configuration of the proximal box cavity, steepness of the cavity walls, and roundness of the internal line angles. The trueness values of the maxillary first molar were significantly higher than those of the maxillary second molar. The higher trueness values at the cavosurface margin of the proximal box in the maxillary first molar may be attributable to the deeper location of the cavosurface margin of the first molar's proximal box, consistent with Nedelcu et al,¹ who reported lower IOS accuracy when the finish line was less distinct. Furthermore, the greater occlusal divergence of the cavity walls in the proximal box and occlusal preparations, coupled with a greater buccal flare of the proximal box, the greater buccolingual width of the proximal box and occlusal cavity in the second molar appear to have reduced the trueness values by improving the straight-line access for light from the IOS to the surface being scanned. This may have reduced cumulative errors in the software stitching process, which likely increases when more images are captured from various angles to cover the uncaptured area, particularly in the case of the narrower, steeper cavity preparations, as in the first molar.

Higher trueness values at the measuring points of the internal line angles in the maxillary first molar than in the second molar may also be attributable to sharper line angles in the preparations of the first molar, which was consistent with Rudolf et al,³⁰ who concluded that

preparation angles should be rounded to reduce digitizing errors. However, if the same cavity preparation were made for first and second molars, the digital scan of the second molar would be more complicated in a clinical setting, and the overall accuracy would be compromised by nonideal positioning of the IOS because of limited mouth opening and space between the prepared tooth and cheek.

Regarding the overall trueness among the measuring points, greater deviation was noted at the line angles at the junction of 2 surfaces in each cavity than at the measuring points on 1 plane. The cusp reduction in the mandibular second premolar was the most accurate area reproduced by the IOSs. This can be explained through undisturbed access during scanning because the cavity was open, without any surrounding cavity walls. The most difficult areas in which to obtain an accurate digital scan were the pulpal line angle in the occlusal cavity preparation and the axiokingival line angle in the box cavity. This finding may be explained by the inherent software limitation of variations in the triangular mesh that tends to lose consistency at the line angle where transition occurs. In addition, greater deviation at the line angles may have arisen from the difficulty of discerning the line angle because light from the IOSs could not be easily directed to the area because of the presence of the surrounding tooth structure. When all trueness values from all cavity preparations were pooled, the axiokingival line angle had the highest overall trueness values. An obstruction or disturbance caused by the presence of axial walls on one side and the marginal ridges of the adjacent tooth on the other seems to have further complicated the scanning process, resulting in lower accuracy. Nevertheless, the trueness of the IOSs at the line angles was improved when the cavity had a greater occlusal divergence and rounded internal line angle.

For CAD-CAM restorations, each wall of a cavity should have occlusal divergence of 6 to 8 degrees for appropriate seating of indirect restorations, and the intaglio aspect of the preparation should be free of sharp angles to reduce stress concentration and to facilitate internal adaptation of the restoration.³¹ Therefore, general CAD-CAM preparation guidelines should be followed not only to satisfy the principles of cavity preparation for indirect restorations but also to improve the accuracy of the IOS scans, as demonstrated in the present study.

A previous study evaluated the trueness of IOSs in obtaining digital scans not only for intracoronal preparations but for the entire surface of each tooth.¹⁰ These findings were consistent with those of the present study, which concluded that the accuracy of IOSs differed depending on the cavity geometry and the type of IOS. However, the previous study addressed the general trend of accuracy of each IOS, whereas the present study focused on the accuracy at various specific locations within a prepared cavity, which is of value in determining the performance of IOSs for cavity configurations in restorative treatment. Therefore, the results of the previous study are not in absolute agreement with the findings of the present study, likely because of the different methodology used for trueness evaluation. In particular, the color-coded deviation map of Zfx IntraScan, provided in the previous study, showed a pronounced positive deviation around the cusp areas.¹⁰ Zfx IntraScan that exhibited the second greatest deviation, followed by E4D, in the previous study showed much less deviation because the deviation within the intracoronal preparations was only measured in the present study.

An antireflective powder coating is required for some IOSs. Controversy exists as to whether powder coating improves the accuracy of IOSs. The application of powder coating has been reported to provide superior,^{21,32} similar,²⁶ and inferior¹⁸ accuracy. Although an excessive powder coat may not significantly decrease scanning performance,²¹ a thin uniform powder coat,

if necessary, would be recommended to minimize the possible negative influence on scanning quality. The effect of powder coating on the performance of IOSs was not considered in the present study because scanning powder was not applied to the master cast prior to scanning, as per the manufacturer's instruction, except for the FastScan.

The performance of IOSs might vary based on the data capture principle (confocal microscopy for iTero, TRIOS, and Zfx IntraScan, triangulation for CEREC Omnicam and FastScan, and optical coherence tomography for E4D) and data capture mode (video sequence for CEREC Omnicam, TRIOS, and Zfx IntraScan, individual image for E4D, FastScan, and iTero). Unfortunately, the direct influence of the data capture principle and data capture mode could not be clearly determined because of the limited number of tested IOSs adopting each scanning technology, as well as differences in the specifications and data processing software of each IOS. The overall trueness of IOSs differed significantly between groups, implying that the performance depends on each individual IOS.

Limitations of the present study included that the results could not be fully extrapolated to the entire surface of the intracoronary preparations despite the analysis of multiple measuring points to represent critical spatial locations. Furthermore, because only the trueness of IOSs was evaluated, the results of the present study may not directly reflect final outcomes because the trueness of CAD-CAM-fabricated definitive restorations can be further influenced by the type of milling machine³³ and the materials used for milling.³⁴

CONCLUSIONS

Based on the findings of the present in vitro study, the following conclusions were drawn.

1. The trueness of digital scans was influenced by the type of IOSs and the location within a cavity. TRIOS was the most accurate and E4D was the least accurate.
2. The trueness of all IOSs decreased where 2 surfaces met. In particular, the axiokingival line angle was the most difficult area from which to acquire accurate geometric data.
3. The trueness of digital scans appeared to be compromised when the cavity was prepared with steep occlusal divergence and sharp line angles.

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TABLES

Table 1. Intraoral scanners tested

System	Manufacturer	Scanner Technology	Light Source	Acquisition Method	Necessity of Coating
CEREC Omniscam	Dentsply Sirona,	Active triangulation with strip light projection	Light	Video sequence	None
E4D dentist (initial version)	E4D Technologies,	Optical coherence tomography	Laser	Individual image	Occasional
FastScan	IOS Technologies, Inc	Active triangulation and Scheimpflug principle	Laser	Individual image	Yes
iTero (1 st generation)	Align Technology Inc	Parallel confocal microscopy	Red laser	Individual image	None
TRIOS (2 nd generation)	3shape A/S,	Confocal microscopy	Light	Video sequence	None
Zfx IntraScan	Zfx GmbH	Confocal microscopy and Moiré effect detection	Laser	Video sequence	None

Table 2. Overall trueness values of intraoral scanners

Variable	MxFP		MxFM		MxSM		MnSP		MnFM		Total		df	Chi-square	P
	Median [Q1–Q3]														
CEREC	26.9	Bbc	35.7	Ca	23.5	Bbc	21.0	Cc	30.4	Bb	26.9	B	4	25.0	<.001
Omnicam	[15.5-42.7]		[17.2-58.3]		[11.5-48.9]		[8.4-36.3]		[16.0-43.8]		[12.8-45.4]				
E4D	80.6	Ab	91.1	Aa	76.7	Ab	54.3	Ab	77.0	Aab	77.5	A	4	71.8	<.001
	[32.4-121.3]		[36.9-164.3]		[24.6-123.2]		[22.6-131.2]		[46.1-125.9]		[31.3-131.4]				
FastScan	28.6	Ba	30.5	Ca	21.8	Cb	21.1	Cb	28.6	Ba	26.1	BC	4	34.4	<.001
	[15.1-45.3]		[16.0-50.1]		[10.9-38.5]		[7.3-33.8]		[16.6-44.9]		[11.9-41.6]				
iTero	26.6	Bab	30.3	Ca	19.4	Cb	21.5	Cb	30.9	Ba	25.4	BC	4	27.0	<.001
	[12.2-40.0]		[14.7-51.4]		[8.9-36.7]		[8.9-33.2]		[18.1-40.9]		[11.3-39.5]				
TRIOS	25.5	Bac	29.9	Ca	15.0	Cd	21.3	Ccd	28.2	Bb	23.9	C	4	12.0	.018
	[9.7-37.6]		[15.9-45.8]		[7.5-30.7]		[8.4-34.2]		[16.3-37.1]		[12.1-37.1]				
Zfx	16.0	Cc	44.2	Ba	24.9	Bb	27.8	Bb	19.5	Cc	24.6	B	4	22.5	<.001
IntraScan	[7.6-29.5]		[25.6-67.7]		[14.4-37.8]		[13.4-48.5]		[8.2-33.2]		[12.8-45.2]				
Total	27.2	bc	37.6	a	23.4	c	24.6	c	30.7	b					
	[13.0-47.1]		[19.2-66.0]		[11.6-48.4]		[11.1-42.6]		[16.5-46.7]						
df	5		5		5		5		5						
Chi-square	89.2		102.8		110.3		136.5		208.3						
P	<.001		<.001		<.001		<.001		<.001						

df, degrees of freedom; P, P value by Kruskal-Wallis test.

MxFP, maxillary first premolar with occlusal cavity; MxFM, maxillary first molar with mesio-occlusal cavity; MxSM, maxillary second molar with mesio-occlusal cavity; MnSP, mandibular second premolar with mesio-occluso-distal cavity and lingual cusp reduction; MnFM, mandibular first molar with bucco-occlusal cavity.

Different uppercase letters within same column indicate statistical difference between IOSs; different lowercase letters within same row indicate statistical difference between cavity designs ($P < .05$).

Table 3. Trueness values of intraoral scanners at each measuring point

Variable	Occlusal cavity								Box cavity							
	Carvosurface		External wall		Pulpal line		Pulpal		Box carvosurface		Gingival		Axiolingival line angle		Axial wall	
	margin				angle		floor		margin		floor					
Median [Q1-Q3]																
CEREC	31.8	B	22.7	B	26.2	C	19.2	D	21.6	C	35.4	B	52.9	C	32.8	AB
Omniscam	[19.1-45.5]		[10.2-41.6]		[13.3-54.1]		[10.0-31.5]		[10.5-27.9]		[17.1-53.2]		[23.9-89.3]		[27.7-66.0]	
E4D	36.8	A	59.8	A	116.4	A	100.9	A	67.4	A	135.6	A	153.0	A	44.0	A
	[22.5-61.3]		[27.9-91.2]		[79.8-167.8]		[75.0-131.9]		[29.1-109.4]		[87.7-166.9]		[89.1-226.1]		[26.7-76.6]	
FastScan	20.9	C	19.7	BC	42.7	B	28.3	C	29.2	BC	25.1	BC	95.6	B	24.8	CD
	[8.6-32.2]		[7.5-33.7]		[25.8-73.7]		[19.9-35.2]		[16.6-43.6]		[16.2-48.0]		[28.9-146.8]		[12.9-35.9]	
iTero	15.2	C	13.7	D	39.6	B	33.6	B	26.9	BC	27.4	C	61.1	C	20.8	D
	[7.3-31.4]		[5.6-26.5]		[28.7-64.3]		[24.4-45.4]		[9.0-52.6]		[11.3-41.3]		[15.1-77.4]		[10.3-31.8]	
TRIOS	19.9	C	8.7	E	36.9	B	33.9	B	23.5	BC	26.8	C	73.1	BC	32.9	BC
	[11.7-28.9]		[3.6-15.7]		[24.7-65.0]		[24.5-39.5]		[11.4-40.5]		[15.9-34.2]		[29.5-93.3]		[17.5-42.2]	
ZFX	21.9	B	14.0	CD	29.2	C	21.5	D	41.0	B	33.3	B	38.8	C	23.9	CD
IntraScan	[11.0-49.0]		[6.1-30.5]		[15.6-40.1]		[9.3-32.5]		[18.6-64.8]		[19.8-54.0]		[14.4-60.6]		[13.2-44.2]	
Total	23.1	e	17.2	f	39.8	b	30.9	d	27.5	d	32.4	cd	65.6	a	28.0	d
	[12.0-42.8]		[6.9-34.9]		[23.6-73.1]		[18.9-44.5]		[12.9-55.0]		[18.8-55.0]		[29.3-103.0]		[15.7-47.0]	
Chi-square	82.7		98.1		138.7		217.7		22.4		115.8		32.3		27.3	
P	<.001		<.001		<.001		<.001		<.001		<.001		<.001		<.001	

Variable	Box cavity										Total	Chi-square	P	
	Axiopulpal angle	line	Box pulpal floor	Box wall	Box line angle	Cusp reduction	Cusp counterbevel							
	Median [Q1-Q3]													
CEREC	20.2	C	10.4 C	11.9	BC	36.8	BC	3.6	31.6	A	26.9	B	83.6	<.001
Omniscam	[9.5-28.9]		[7.0-14.9]	[5.7-37.7]		[18.9-62.2]		[1.6-9.7]	[27.3-36.4]		[12.8-45.4]			
E4D	30.9	AB	77.5 A	42.6	A	163.4	A	15.2	19.8	A	77.5	A	229.2	<.001
	[17.5-45.9]		[40.7-89.7]	[16.6-84.4]		[101.1-190.8]		[4.7-22.6]	[13.6-63.4]		[31.3-131.4]			
FastScan	21.2	BC	15.9 BC	18.1	BC	30.2	CD	5.7	15.0	B	26.1	BC	87.8	<.001
	[6.1-44.7]		[5.8-29.8]	[7.3-36.6]		[9.4-42.7]		[3.9-8.3]	[7.5-19.9]		[11.9-41.6]			

iTero	21.7 [9.5-28.8]	BC	21.7 AB [14.1-31.5]	16.5 [5.8-27.3]	BC	32.0 [15.2-45.4]	CD	3.6 [3.4-7.3]	1.5 [0.8-4.8]	C	25.4 [11.3-39.5]	BC	158.6	<.001
TRIOS	18.2 [8.4-37.8]	C	21.2 AB [14.0-28.5]	13.7 [3.6-27.9]	C	24.5 [16.4-41.2]	D	1.9 [1.0-5.2]	5.9 [4.0-7.5]	C	23.9 [12.1-37.1]	C	179.9	<.001
ZFX	34.7 [26.2-61.8]	A	22.7 A [12.5-41.4]	19.7 [8.1-32.4]	B	36.5 [19.6-74.4]	B	5.8 [1.74-16.5]	42.3 [27.7-58.0]	A	24.6 [12.8-45.2]	B	75.0	<.001
IntraScan														
Total	23.6 [11.9-40.5]	e	21.4 ef [12.1-33.5]	18.9 [6.8-35.0]	f	36.8 [19.4-67.8]	bc	5.3 [2.04-10.0]	14.9 [5.45-36.4]	g	f		28.4 [13.8-49.0]	
Chi-square	20.8		57.5	31.2		93.5		6.9	20.2					
P	.001		<.001	<.001		<.001		.232	.001					

df, degrees of freedom; *P*, *P* value by Kruskal-Wallis test.

MxFP, maxillary first premolar with occlusal cavity; MxFM, maxillary first molar with mesio-occlusal cavity; MxSM, maxillary second molar with mesio-occlusal cavity; MnSP, mandibular second premolar with mesio-occluso-distal cavity and lingual cusp reduction; MnFM, mandibular first molar with bucco-occlusal cavity.

Different uppercase letters within same column indicate statistical difference between IOSs; different lowercase letters within same row indicate statistical difference between cavity designs ($P < .05$).

FIGURES

Figure 1. Intracoronral cavity preparations of master cast. A, Occlusal preparation on maxillary first premolar. B, Mesio-occlusal preparation on maxillary first molar. C, Mesio-occlusal preparation on maxillary second molar. D, Mesio-occluso-distal preparation with lingual cusp reduction on mandibular second premolar. E, Bucco-occlusal preparation on mandibular first molar.

Figure 2. Measuring points within intracoronral preparation. a-d, in occlusal cavity; e-l, in box cavity; m-n, cusp capping area. a, cavosurface margin; b, external wall; c, pulpal line angle; d, pulpal floor; e, cavosurface margin; f, gingival floor; g, axiokingival line angle; h, axial wall; i, axiopulpal line angle; j, pulpal floor; k, box wall; l, box line angle; m, cusp reduction; n, cusp counterbevel.

Figure 3. Deviation (μm) of digital scan acquired by intraoral scanners at measuring points for each tooth.