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Evaluating the accuracy of CEREC intraoral scanners for inlay restorations: impact of adjacent tooth materials

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Abstract

Background The accuracy of intraoral scanning is critical for computer-aided design/computer-aided manufacturing workflows in dentistry. However, data regarding the scanning accuracy of various adjacent restorative materials and intraoral scanners are lacking. This in vitro study aimed to evaluate the effect of adjacent restorative material type and CEREC's intraoral scanners on the accuracy of intraoral digital impressions for inlay cavities.

Methods The artificial tooth was prepared with an occlusal cavity depth of 2 mm, a proximal box width at the gingival floor of 1.5 mm, and an equi-gingival margin extended disto-occlusally at the transition line angle on both the lingual and buccal sides for an inlay restoration. The adjacent teeth were veneered with crowns made of gold and zirconia, and an artificial tooth (resin) was utilized as the control group. The inlay cavity and adjacent teeth (Gold, Zirconia, and resin) were scanned 10 times using Chairside Economical Restoration of Esthetic Ceramics (CEREC) Primescan (PS), Omnicam (OC), and Bluecam (BC). A reference scan was obtained using a laboratory scanner (3-shape E3). Scanning was performed according to the manufacturer's instructions, including powder application for the BC group. Standard tesselation language files were analyzed using a three-dimensional analysis software program. Experimental data were analyzed using a two-way analysis of variance and the Tukey's post-hoc comparison test.

Results The restorative materials of the adjacent teeth significantly affected the accuracy of the intraoral digital impressions ($p < .05$). The zirconia group exhibited the highest trueness deviation, followed by the resin and gold groups, with each demonstrating a statistically significant difference ($p < .05$). The resin group demonstrated the highest maximum positive deviation and deviation in precision. Gold exhibited the lowest average deviation value for trueness compared with those of the other adjacent restorative materials. Intraoral scanner type significantly influenced the trueness and precision of the scan data ($p < .05$). The average deviation of trueness according to the intraoral scanner type increased in the following order: BC > PS > OC. The average deviation in precision increased in the following order: PS>OC>BC ($p < .05$).

Conclusion The restorative materials of the adjacent tooth and the type of intraoral scanner affect the accuracy of the intraoral digital impression. The trueness of the digital images of the BC group, obtained by spraying the powder, was comparable to that of the PS group. Among the adjacent restorative materials, zirconia exhibited the lowest trueness. In contrast, PS demonstrated the highest precision among the intraoral scanners, while resin displayed the lowest precision among the adjacent restorative materials.

Keywords Inlay restoration, Intraoral scanner, CAD/CAM, Accuracy, Trueness, Precision

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Background

Advances in computer-aided design/computer-aided manufacturing (CAD/CAM) systems have enabled a fully digital workflow for fabricating indirect restorations in dental practice. Compared to existing conventional impression technologies, CAD/CAM has the advantage of reducing treatment time and increasing convenience for patients and operators [1, 2]. Recently, as the use of CAD/CAM has increased, the accuracy of intraoral scanner (IOS) has achieved qualitative development comparable to that of conventional impression technology, and qualitative evaluation of this is increasing in recent studies, so it is necessary to learn more about this [3, 4]. In 1985, Dentsply Sirona introduced the first chairside CAD/CAM workflow, Chairside Economical Restoration of Esthetic Ceramics (CEREC), whose intraoral scanners have evolved into Redcam, Bluecam, Omnicom, and Primescan. Redcam is an early intraoral scanner developed by CEREC that uses an infrared laser camera [5]. The Bluecam is based on the basic principles of confocal microscopy and is an active triangulation technique using blue light-emitting diodes. A single image is then captured by treating the surface with titanium dioxide powder, which is required for capturing the surface anatomy [6]. Omnicam and Primescan are color video speed-scanning systems that do not require the use of powder. They employ video technology utilizing active triangulation and emitting white light to measure surfaces, capturing the anatomy and color of the oral tissue using a wide-focal-depth camera [7, 8]. Primescan has a depth of field (DOF) of approximately 20 mm, which is greater than that of Omnicam [9].

Trueness and precision were defined by the International Organization for Standardization (ISO) as terms for evaluating the accuracy of digital scan data (ISO-5725–1). Trueness is the distance between a measured value and the true or actual value of the measured object. Conversely, precision indicates the closeness of the measured value and serves as a measure of measurement repeatability [9]. The accuracy of the intraoral scanner (IOS) is affected by the restorative material, including the material type, translucency, and surface finishing. In previous studies, inconsistencies in the reflection properties of various restorative materials have affected the accuracy of IOS. The accuracy of IOS may be reduced if the teeth being scanned have restorations or restorative materials that are highly translucent [10–14]. Bockletet et al. reported that both the type of restorative material and the type of intraoral scanner affected the accuracy of the scan data [15]. However, a lack of literature exists regarding the accuracy of IOS for inlay restorations depending on the type of adjacent restorative material. In addition, although CEREC have developed into a worldwide system, there are few literatures comparing them together, and there are no literatures comparing how mode changes due to development affect accuracy.

The purpose of this in vitro study was to evaluate the impact of the type of adjacent restoration material and intraoral scanner on the accuracy of digital scans of the inlay cavity and intraoral digital impressions using three intraoral scanners from a single manufacturer. The null hypotheses were that (1) the type of adjacent material does not affect the accuracy of digital scan data and (2) the type of intraoral scanner does not affect the accuracy of digital scan data.

Methods

The overall workflow of this study is illustrated in Fig. 1. The disto-occlusal (DO) inlay cavity of an artificial mandibular right first molar (A5AN-500; Nissin Dental) was prepared by an operator under a microscope (M320 F12, Leica Instruments) using an inlay preparation diamond dental bur (Inlay prep bur kit 4261; SUNGSHIM Dental). The occlusal cavity was prepared with a width of 3.5 mm and a depth of 2.0 mm. Additionally, the proximal box was formed with a width of 1.5 mm and a depth of 2.0 mm, while the DO equi-gingival margin was extended to the transition line angle on both the lingual and buccal sides. The inner wall had a divergence of 10–15 degrees and all line angles were rounded.

To prepare the adjacent tooth, two artificial mandibular right second molars (A5AN-500; Nissin Dental) were scanned using IOS (CEREC Primescan AC v. 5.1.0, Dentsply Sirona) after tooth preparation for the zirconia and gold single-veneer crowns. Zirconia and gold-crown were fabricated on the acquired scan images using CAD/CAM (Primescan, CEREC). The fabricated zirconia and gold crowns were cemented with self-adhesive resin cement (G-CEM ONE, GC) on each tooth (Figs. 2a, b). An unprepared artificial mandibular right second molar was used as a control (Fig. 2c).

Reference scan data for the combination of the mandibular right first molar with the DO inlay cavity and adjacent teeth composed of three materials, zirconia, gold, and resin (control), were scanned using a reference scanner (3Shape E3; 3Shape A/S) and converted to Standard Tessellation Language (STL) files.

Three intraoral scanners were employed: the CEREC Primescan, CEREC Omnicam, and CEREC Bluecam (Table 1). Furthermore, IOS images of the mandibular right first molar with a DO inlay cavity and the second molar comprising a gold crown, zirconia crown, and artificial tooth were obtained 10 times for each group. A dental phantom head was used to replicate the clinical environment. The scanning procedure was performed according to the manufacturer's instructions, and only

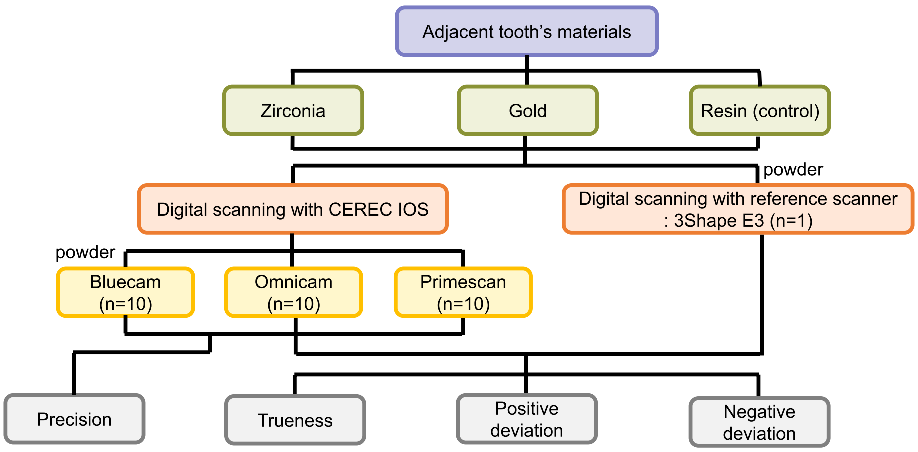

Fig. 1 Schematic workflow of the study

Fig. 2 Disto-occlusal inlay cavity and adjacent tooth material types. **a** Zirconia. **b** Gold. **c** Resin (control)

the Bluecam group was sprayed with the powder. The scanning sequence was performed in a mesial direction, starting from the distal end of the dentition in the occlusal plane, and then the buccal and lingual surfaces were scanned in angulated directions.

The acquired scanned data were exported as raw STL files. A three-dimensional (3D) inspection software program (GOM Inspect 2018; GOM GmbH) was used to evaluate the accuracy of the scanned data for the experimental model. The trueness of the experimental model was analyzed by superimposing the reference and STL data using the initial alignment and 3D best-fit alignment methods ($n=10$ each). The scan data were quantified using the average deviation. In addition, the mean maximum positive and negative deviations were calculated to evaluate the size of the local deviation in trueness. In each experimental group, each STL file was superimposed with other data to determine precision, employing both the initial alignment and 3D best-fit alignment methods consistently ($n=45$). The experimental data were analyzed using a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp.). Two-way analysis of variance (ANOVA) and Tukey's post-hoc comparison test were used to compare the types of adjacent tooth material and intraoral scanners ($\alpha=0.05$). A post- hoc power analysis was performed to evaluate the effect size and statistical power of the study using actual data after the study was conducted. The effect size was calculated by comparing mean values and using the Practical Meta-Analytic effect size calculator to calculate Cohen's d, and statistical power was calculated using G-power software.

Results

Table 2 displays the mean deviations of the variables for all experimental groups. In terms of the trueness deviation, Omnicam-Zirconia demonstrated the highest deviation (21.7 ± 0.3), and Bluecam-Gold demonstrated the lowest deviation (9.6 ± 0.7). The precision deviation was notably high value in the Bluecam group (Bluecam-Zirconia, 6.5 ± 0.7; Bluecam-Resin, 9.3 ± 1.4), regardless of the adjacent materials, while the primescan group exhibited low values (Primescan-Zirconia, 2.3 ± 0.2, Primescan-Gold, 2.5 ± 0.3).

Different superscript letters within same parameter indicate statistically significant differences by Tukey's post-hoc comparison test ($p<0.05$).

Table 3 displays the statistical results of the two-way ANOVA concerning the average deviation for trueness,

Table 1 Comparison of intraoral scanners used in the experiment

	Bluecam	Omnicam	Primescan
Manufacturer	Dentsply Sirona	Dentsply Sirona	Dentsply Sirona
Scan method	Confocal	Confocal	Confocal
Light source	Blue light-emitting diode	Light-emitting diode	Light-emitting diode
Acquisition method	Still imaging	Video	Video
Powder use	Required	Not required	Not required
Anti-reflection		No	Yes, chemically abraded
Scanner head (W x H)	17 × 22 mm	16 × 16 mm	22.5 × 20.7 mm

W Width, *H* Height

Table 2 Mean ± standard deviation (μm) values for parameters across all experimental group

Parameter		Bluecam	Omnicam	Primescan
Average deviation for trueness	Zirconia	14.0 ± 0.6^{A}	21.7 ± 0.3^{D}	19.3 ± 0.3^{F}
	Gold	9.6 ± 0.7^{B}	12.7 ± 0.3^{E}	11.1 ± 0.3^{G}
	Resin (control)	12.0 ± 0.9^{C}	14.6 ± 0.3^{A}	11.6 ± 0.4^{CG}
Mean maximum positive deviation	Zirconia	144.0 ± 21.7^{A}	145.0 ± 20.7^{A}	150.0 ± 11.5^{A}
	Gold	142.0 ± 20.4^{A}	189.0 ± 14.5^{BC}	120.0 ± 8.1^{D}
	Resin (control)	177.0 ± 17.0^{B}	200.0 ± 0.0^{C}	172.0 ± 4.2^{B}
Mean maximum negative deviation	Zirconia	74.0 ± 13.5^{A}	120.0 ± 38.0^{AB}	98.0 ± 33.3^{AB}
	Gold	78.0 ± 26.2^{A}	124.0 ± 46.5^{AB}	119.0 ± 39.8^{AB}
	Resin (control)	93.4 ± 54.9^{AB}	126.0 ± 24.1^{AB}	145.0 ± 38.1^{B}
Average deviation for precision	Zirconia	6.5 ± 0.7^{A}	4.1 ± 0.3^{C}	2.3 ± 0.2^{D}
	Gold	6.9 ± 0.7^{A}	4.5 ± 0.5^{C}	2.5 ± 0.3^{D}
	Resin (control)	9.3 ± 1.4^{B}	4.2 ± 0.4^{C}	2.4 ± 0.3^{D}

Table 3 Results of two-way analysis of variance for parameters

Parameter	Source	df	SS	MS	F	*p*-value
Average deviation for trueness	Adjacent materials	2	868.3	434.1	1740.0	< .001
	Intraoral scanner	2	302.5	151.3	606.2	< .001
	Adjacent materials x Intraoral scanner	4	110.5	27.6	110.7	< .001
Mean maximum positive deviation	Adjacent materials	2	24275.6	12137.8	53.7	< .001
	Intraoral scanner	2	15495.5	7747.8	34.3	< .001
	Adjacent materials x Intraoral scanner	4	14017.8	3504.4	15.5	< .001
Mean maximum negative deviation	Adjacent materials	2	8851.5	4425.7	3.3	.043
	Intraoral scanner	2	32427.5	16213.7	12.0	< .001
	Adjacent materials x Intraoral scanner	4	4520.3	1130.1	0.8	.508
Average deviation for precision	Adjacent materials	2	69.8	34.9	83.9	< .001
	Intraoral scanner	2	1833.3	916.6	2203.0	< .001
	Adjacent materials x Intraoral scanner	4	141.5	35.4	85.0	< .001

df degrees of freedom, *MS* Mean square, *SS* Sum of squares

Table 4 Comparisons between adjacent tooth materials for average deviation for trueness, mean maximum deviations, and precision (µm)

Adjacent tooth materials	Average deviation for trueness	Mean maximum positive deviation	Mean maximum negative deviation	Average deviation for precision
Zirconia	18.4 ± 3.3^{A}	146.3 ± 18.1^{A}	97.3 ± 34.8^{A}	4.3 ± 1.8^{A}
Gold	11.1 ± 1.4^{B}	150.3 ± 32.7^{A}	107.0 ± 42.6^{A}	4.7 ± 1.9^{A}
Resin (control)	12.7 ± 1.5^{C}	183.0 ± 15.8^{B}	121.5 ± 45.1^{A}	5.3 ± 3.1^{B}

Different superscript letters within the same column indicate statistically significant differences between adjacent tooth materials ($p < .05$)

Table 5 Comparisons between intraoral scanner types for average deviation for trueness, mean maximum deviations, and precision (µm)

Intraoral scanner types	Average deviation for trueness	Mean maximum positive deviation	Mean maximum negative deviation	Average deviation for precision
Bluecam	11.8 ± 2.0^{A}	154.3 ± 25.1^{A}	81.8 ± 35.7^{A}	7.6 ± 1.6^{A}
Omnicam	16.3 ± 4.0^{B}	178.0 ± 28.0^{B}	123.3 ± 36.1^{B}	4.3 ± 0.5^{B}
Primescan	14.0 ± 3.8^{C}	147.3 ± 23.2^{A}	120.7 ± 40.8^{B}	2.4 ± 0.3^{C}

Different superscript letters within the same column indicate statistically significant differences between the intraoral scanner types ($p < .05$)

mean maximum positive deviation and negative deviation, and average deviation for precision, considering the adjacent material and types of intraoral scanners. The adjacent material and intraoral scanner type had statistically significant effects on each of the four parameters ($p < 0.05$). The interaction between the adjacent material and intraoral scanner had a significant impact on all parameters, except the mean maximum negative deviation ($p < 0.05$).

Table 4 presents the results for each variable within each adjacent material group. The average deviation for trueness of the cavity depending on the material of the adjacent teeth ranged from 11.1 ± 1.4 to 18.4 ± 13.3 µm. The gold group exhibited the lowest average trueness deviation, followed by the resin and zirconia groups. Statistically significant differences were observed depending on the material used ($p < 0.05$). The average range of maximum positive deviation ranged from 146.3 ± 18.1 to 183.0 ± 15.8 µm, meanwhile, the average range of precision deviation was 4.3 ± 1.6–5.3 ± 3.1 µm. The highest mean maximum positive deviation and average deviation for precision were identified in the resin group (control), demonstrating statistical differences from the other adjacent material groups ($p < 0.05$). However, no significant difference was observed between the zirconia and gold groups in terms of the mean maximum positive deviation and mean precision deviation. In contrast, the average range of maximum negative deviation was 97.3 ± 34.8 to 121.5 ± 45.1 µm. No statistically significant differences were observed among the zirconia, gold, and resin groups ($p > 0.05$).

Table 5 displays the results of each parameter for each intraoral scanner type. The average deviation range of trueness according to intraoral scanner type was 11.8 ± 2.0 to 16.3 ± 4.0 mm. The lowest average trueness deviation was observed in the Bluecam group, followed by the Primescan and Omnicam groups. Statistically significant differences were observed between the groups ($p < 0.05$). The mean range of maximum positive deviation was 147.3 ± 23.2 to 178.0 ± 28.0 mm. The Omnicam group demonstrated the highest mean value of the maximum positive deviation ($p < 0.05$), with no statistically significant difference between the remaining groups. The mean range of maximum negative deviation was 81.8 ± 35.7 to 123.3 ± 36.1 mm. The Bluecam group exhibited the lowest mean value of the maximum negative deviation ($p < 0.05$). Additionally, no statistically significant difference was observed between the remaining groups. The average deviation range of precision was 2.4 ± 0.3 to 7.6 ± 1.6 mm. The lowest average deviation in precision was observed for the Primescan group, followed by the Omnicam and Bluecam groups. Statistically significant differences were identified between the groups ($p < 0.05$). In a post-hoc power analysis conducted after the study, the statistical power was 0.82. Figure 3 shows the pattern of positive deviation and negative deviation in the color-coded map overlapped with the reference image.

Discussion

This study aimed to evaluate the effects of the type of adjacent restoration material and intraoral scanner on the accuracy of intraoral digital impressions of the #46

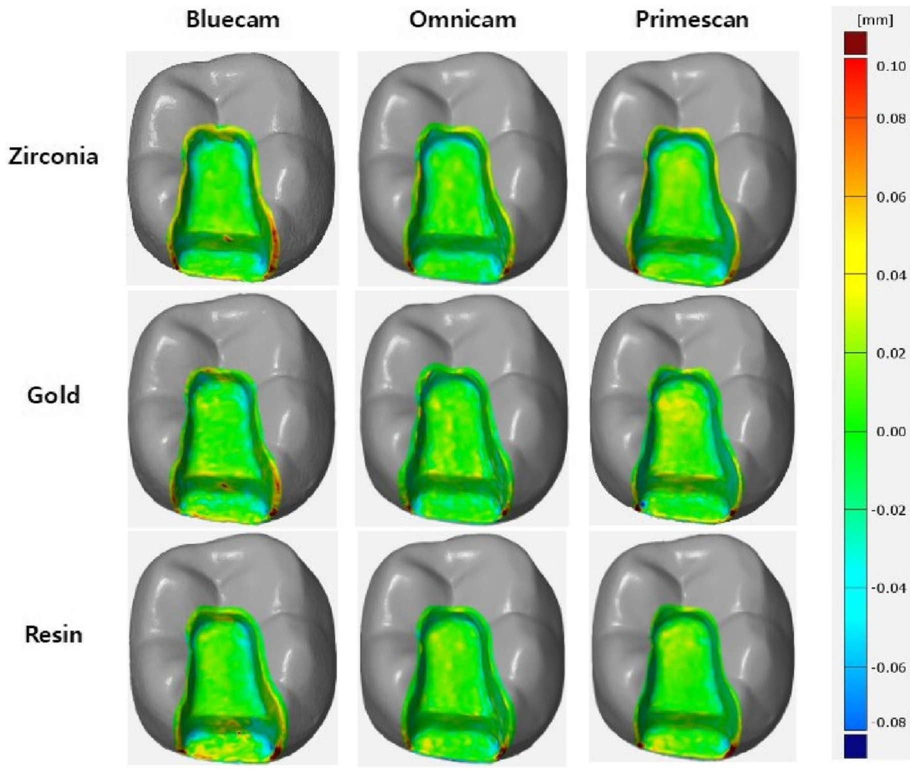

Fig. 3 Qualitative analysis of trueness in tested groups of adjacent tooth materials and intraoral scanner types

DO cavity. In this study, two factors, adjacent material, and intraoral scanner type had a statistically significant effect on each of the four parameters ($p < 0.05$). Therefore, the first and second null hypotheses, that the type of adjacent material and type of intraoral scanner would not affect the accuracy of the digital scan data, were rejected.

In this study, a dental phantom head model was utilized to reproduce the intraoral conditions commonly encountered in clinical situations. A desktop laser scanner (E3, 3Shape) was used as the reference scanner. According to the manufacturer, the E3 scanner has an accuracy of 7 µm attributed to its implementation of a technology called Blue LED Multiline. This has been widely selected as the reference scanner in recent IOS accuracy studies [16].

In this study, the restorative material of the adjacent teeth had a statistically significant effect on the average deviation of trueness, mean maximum positive deviation, and average deviation of the precision of the inlay cavity ($p < 0.05$). Before interpreting the variable values of the experimental group, it should be noted that low mean deviation values indicate high trueness or precision of the scan data obtained from the IOS. Differences in the optical properties of teeth and dental materials can influence the scan accuracy. The presence of restorations in teeth can potentially reduce the accuracy of intraoral scanning [11–14]. This is due to the inherent influence of light dispersion and uniformity on intraoral scanners, whereby the surface characteristics of surrounding teeth and restorations can affect the scan results [13]. The results of this experiment demonstrated that the trueness average deviation value was highest when the adjacent tooth material was zirconia and lowest when the adjacent tooth material was gold. Dutton et al. discovered that more translucent materials, such as enamel shade composites, natural enamel, and lithium disilicate, negatively affected trueness, whereas more reflective materials, such as polished gold or amalgam, had no significant negative effect [12]. This finding is consistent with the results of the present study. Previous studies have demonstrated that the presence of metallic materials has a negative impact on scanning accuracy when using IOS [15]. Therefore, previous studies recommended the use of powders to overcome the problems associated with surface moisture and angular reflections [11, 17]. In this study, among the three IOSs, powder was utilized only for Bluecam in accordance with the manufacturer's instructions. The results demonstrated that the gold group of Bluecam when sprinkled with powder, exhibited the lowest trueness deviation value. In addition, the lowest trueness deviation observed with Bluecam among the IOS is believed to be attributed to the effect of powder, which diminishes the difference in the optical properties of dental materials.

In general, IOS can be categorized based on their data capture principle, which includes active triangulation, confocal microscopy, optical coherence tomography, or active wavefront sampling [18]. The Bluecam, Omnicam, and Primescan used in this study operate based on both optical triangulation and confocal microscopy [6, 7, 19]. Table 1 displays a comparison of Bluecam, Omnicam, and Primescan. The results of this study demonstrated that the average deviation for trueness among intraoral scanner types was lowest in Bluecam followed by Omnicam and Primescan, respectively ($p > 0.05$). The Bluecam utilizes highly accurate blue light scanning technology employing short wavelengths [20]. The Bluecam scanning process requires a thin layer of powder to create a matte finish on the surface and prevent reflection during image capture [21]. A matte finish can enhance the detection of the finish line of the preparation and thus improve the marginal adaptation [22]. The Omnicam, a Primescan scanner technology, is based on an optical 3D video scanner system that captures data in real color in real-time and can generate multiple 3D video data images per second without the need for powder application [21].

Ender et al. analyzed the trueness and precision of four IOS and four different impression materials and concluded that digital systems based on single image stitching technology (for example, iTero and CEREC Bluecam) displayed local deviation at the end of the arch, whereas video-based systems (CEREC Omnicam and Lava COS) demonstrated compression of the arch [23]. Additionally, a recent study comparing Bluecam and Omnicam for marginal discrepancy of crowns demonstrated that crowns produced with the Omnicam scanner system had significantly higher vertical discrepancy values than those produced with the Bluecam scanner system. Moreover, the powder application before Omnicam scanning increased the vertical fit of the crown [24]. These results are partially consistent with those of the present study for the Bluecam and Omnicam. In addition, in this study, intraoral impressions were obtained according to the manufacturer's recommendations, and powder was applied to the subjects only in the Bluecam group, which affected the accuracy of the scanned images.

In this study, both Omnicam and Primescan were video-based systems. The Omnicam had the lowest values for trueness and precision. On the other hand, Primescan demonstrated the lowest precision deviation regardless of the materials. Primescan has a DOF of approximately 20 mm, which is greater than that of the previous Omnicam. This is advantageous for reproducing the sharpness of edges [25]. Primescan features an improved anti-reflection function compared to Omnicam. According to the manufacturer, while Omnicam lacks anti-reflection, Primescan incorporates a chemically abraded anti-reflection mechanism. The Primescan used in this study has a DOF of approximately 20 mm, which is greater than that of Omnicam [26]. These features of Primescan reduce the discrepancy in reflection characteristics between various restorative materials, which can affect the accuracy of the IOS.

Despite spraying the powder, the Bluecam demonstrated the lowest precision. This can be attributed to the advancement of cameras, such as Bluecam, Omnicam, and Primescan.

Deviations between the positive and negative values were related to clinically relevant parameters. Positive deviations can result in short margins and large interfacial mismatches, resulting in debonding. In contrast, negative deviations can cause incomplete seating of the restoration, resulting in incorrect and premature contact with the opposing teeth [18, 25, 26]. As a result of this experiment, the average value of the maximum positive deviation was higher than the average value of the maximum negative deviation for both adjacent tooth materials and intraoral scanner types. Among the adjacent tooth materials, the resin group demonstrated a significantly high average value of maximum positive deviation ($p < 0.05$). Additionally, no significant difference was observed in the average value of maximum negative deviation between materials. Among the intraoral scanner types, Omnicam had the highest average value of the maximum positive deviation and the highest average value of the maximum negative deviation. As illustrated in the color-coded map in Fig. 2, positive deviations were mainly observed at the margin of the proximal box, particularly when the gingival margin intersected with the buccal and lingual margins. This was consistent with the results of a previous study in which deviations appeared in areas of rapid change in curvature within the cavity, as reported by Zimmermann et al. [27].

The limitations of this study are that it was conducted in vitro, which is different from the intraoral environment where saliva and soft tissues exist, and was conducted on artificial teeth. Natural human enamel has different optical properties than artificial resin teeth, so further studies under in vivo conditions are needed to support the results of this study [15]. In this study, the type of IOS and the material of the adjacent teeth affected trueness and precision. There are many factors that affect the scanning accuracy of IOS, and the latest articles divides them into 'operator factors' and 'patient factors' [28, 29]. Future studies need to focus on controllable operator and patient factors to maximize the accuracy of IOS. Studies are needed on more accurate cavity preparation design, scanning pattern, scanning angle and distance, and scanning time to overcome other uncontrollable influences.

Conclusion

Within the limitations of the current in vitro study, the restorative material of the adjacent teeth and the type of intraoral scanner influenced the accuracy of intraoral digital intraoral scanner impressions.

Regarding materials, trueness appears to be advantageous when using powders such as with Bluecam. Particularly for gold, even with the static imaging method, the application of powder appears to demonstrate high accuracy, particularly in terms of trueness. Zirconia demonstrated the lowest trueness, regardless of the IOS type. In IOS, precision increased with the latest equipment in the following order: bluecam, omnicam, and primescan, regardless of the adjacent tooth materials, but trueness was affected by type of materials. Therefore, in order to minimize the influence of materials, it is recommended to use other additional methods, such as more explicit cavity preparation and sufficient scanning time, which can increase IOS accuracy when restorations are present on adjacent teeth; rather than spraying powder, which can complicate the clinical process.

Abbreviations

CAD	Computer-assisted-design
CAM	Computer-assisted-manufacturing
CEREC	Chairside Economical Restoration of Esthetic Ceramics
DOF	Depth of field
ISO	International Organization for Standardization
IOS	Intraoral scanner
STL	Standard tessellation language

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Not applicable.

Authors' contributions

All authors contributed substantially to this study. In detail, YJK, SAS, and JKP contributed to the conception and design of the study and edited and revised the manuscript before submission. YJK drafted the manuscript. JHK attributed with acquisition of data's statistical evaluation. All the authors have read and approved the final version of the manuscript.

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Availability of data and materials

The STL files and 3D surface models obtained in this study with the IOS, as well as the reference files obtained with the laboratory scanner, belong to the School of Dentistry, Pusan National University, and are therefore available only upon reasonable request after approval by the university. The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable. None of the human data were used in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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