



Influence of adjacent restorative material and distance on the accuracy of inlay cavity impressions with intraoral scanner: an *in vitro* study

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ABSTRACT

Objectives: This study aimed to evaluate the influence of adjacent restorative material and interproximal distance on the accuracy of digital impressions of inlay cavities obtained using an intraoral scanner.

Methods: A disto-occlusal inlay cavity was prepared on a mandibular right first molar model, and digital scans were performed using a CEREC Primescan (Dentsply Sirona). The adjacent restorative materials used were Lava (3M ESPE), ENAMIC (VITA Zahnfabrik), Celtra Duo (Dentsply Sirona), and DMAX (DMAX), and the interproximal distances were set to 0.6 mm, 0.8 mm, and 1.0 mm. The obtained scan data were analyzed using GOM Inspect software (GOM GmbH).

Results: Trueness, maximum positive and negative deviations, and precision were significantly influenced by both the adjacent restorative material and the interproximal distance, while their interaction showed a significant effect only on precision. Celtra Duo demonstrated the highest trueness, with mean deviation values decreasing from 7.8 μ m at a 0.6 mm interproximal distance to 7.3 μ m at 1.0 mm. ENAMIC showed the best precision, presenting mean deviations of 2.6 μ m at 0.6 mm, 2.9 μ m at 0.8 mm, and 2.4 μ m at 1.0 mm. A narrow interproximal distance of 0.6 mm resulted in lower trueness, measured at 8.3 μ m, and the highest precision deviation of 3.4 μ m. In contrast, an interproximal distance of 1.0 mm yielded improved scan accuracy, with increased trueness and reduced precision variation.

Conclusions: Digital impression accuracy of inlay cavities was influenced by adjacent restorative material and interproximal distance, suggesting clinical consideration is needed in CAD/CAM workflows to optimize restoration fit.

Keywords: Digital impression accuracy; Interproximal distance; Inlay cavity; Intraoral scanner; Restorative materials

Received: June 12, 2025 **Revised:** July 22, 2025 **Accepted:** August 19, 2025

Citation

Lee SY, Son SA, Kim JH, Seo DG, Park JK. Influence of adjacent restorative material and distance on the accuracy of inlay cavity impressions with intraoral scanner: an *in vitro* study. Restor Dent Endod 2026;51(1):e6.

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INTRODUCTION

Digital scanning technology using intraoral scanners has become an essential process in fabricating dental restorations alongside advances in computer-aided design/computer-aided manufacturing (CAD/CAM) systems [1,2]. This technology enables minimal removal, accurate impression acquisition, and efficient workflow while significantly reducing potential distortion or deformation associated with conventional impression materials. These advantages make digital scanning a critical factor in enhancing clinical success and patient satisfaction [3–5].

The accuracy of intraoral scanners is essential when determining the fit and clinical success of final restorations [6,7]. Accuracy consists of two fundamental concepts: trueness and precision. Trueness refers to how closely the measured result matches the actual value, with a lower deviation from the true form indicating higher trueness. Precision refers to the consistency of repeated measurements under the same conditions, where higher consistency among values indicates higher precision [8]. Therefore, accuracy encompasses trueness and precision, and a balance of these two factors is essential to produce high-quality restorations.

The intraoral environment, with factors such as saliva, varying refractive indices of the teeth and gingiva, and limited oral opening, can reduce the scanning accuracy [9]. In particular, the restorative material of the adjacent teeth may alter the reflection and absorption properties of the scanner's light, affecting the quality of scan data [10]. Various restorative materials commonly used in CAD/CAM systems, including resin, hybrid ceramic, lithium silicate, and zirconia, may reduce the clarity of boundary delineation in digital impressions because of differences in refractive indices. In addition, the scanner's field of view becomes restricted as the interproximal distance to adjacent teeth decreases, potentially lowering the scan quality and adversely affecting the fit of the final restoration [11].

When scanning an inlay cavity with an intraoral scanner, the distance to the adjacent restorations is critical in determining the scanning accuracy [12]. Typically, when forming an inlay cavity, maintaining an approximately 0.5 mm gap, including the proximal box with

the adjacent tooth, is essential for establishing proper proximal contact [13]. If the distance to the adjacent tooth is too narrow, the scanning beam may fail to reach the deeper areas of the cavity, or excessive light reflection may occur at the interproximal contact point, making accurate impression acquisition challenging [14]. Therefore, the type of restorative material and the distance to the adjacent tooth can directly affect the accuracy of cavity scanning, which, in turn, can affect the fit of the final restoration.

Nevertheless, research on the effects of external factors, such as the type of adjacent restorative material and interproximal distance, on the scanning accuracy of the CEREC Primescan (Dentsply Sirona, Charlotte, NC, USA) remains limited. Therefore, this study examined the effects of adjacent restorative materials and interproximal distances to optimize the digital scan accuracy of inlay cavities and provide foundational data for minimizing clinical errors in digital impression acquisition using CAD/CAM systems. This study examined how adjacent restorative materials and interproximal distance affect the digital scan accuracy of inlay cavities.

Based on this, the following null hypotheses were tested: (1) adjacent restorative materials do not have a significant effect on the accuracy of digital scans; (2) the interproximal distance does not have a significant effect on the accuracy of digital scans; (3) the interaction between adjacent restorative materials and the interproximal distance does not have a significant effect on the accuracy of digital scans.

METHODS

Inlay cavity preparation

A disto-occlusal inlay cavity on an artificial mandibular right first molar was formed. A 3Shape scanner (3Shape E3; 3Shape A/S, Copenhagen, Denmark) was used to scan an artificial tooth, and a cavity design was then formed using Meshmixer software (Autodesk Meshmixer, ver. 3.5; Autodesk Inc., San Rafael, CA, USA). The cavity was designed with an occlusal depth of 2 mm and a proximal box width of 1.5 mm, extending in the disto-occlusal direction with the margins aligned horizontally to the gingiva and adapted to the transitional angles on the lingual and buccal surfaces. The mandib-

ular right first molar model with the designed cavity was printed using a three-dimensional (3D) printer (3Shape E3).

Reference scan

The reference scan data for the disto-occlusal inlay cavity were obtained using the same 3Shape scanner. The scanned data were converted into a Standard Tessellation Language (STL) file.

Preparation process for adjacent teeth

The restorative materials for the adjacent tooth included Lava Ultimate CAD/CAM Restorative (3M ESPE, St. Paul, MN, USA), VITA ENAMIC (VITA Zahnfabrik, Bad Säckingen, Germany), Celtra Duo (Dentsply Sirona, Hanau, Germany), and DMAX CAD/CAM Blocks (DMAX, Daegu, Korea). The artificial mandibular right second molar (A5AN-500; Nissin Dental, Kyoto, Japan), used as the adjacent tooth, underwent preparation and was then scanned with an intraoral scanner (IOS; CEREC Primescan AC ver. 5.1.0, Dentsply Sirona).

Based on the scanned image, a crown was fabricated using CAD/CAM (CEREC Primescan). All four materials used in this study used A2 shaded blocks. The adjacent restorations were fabricated by a single skilled technician, following the manufacturer's instructions for each block. The surface polishing of the milled restorations was performed under the same conditions. The fabricated crown was cemented onto the adjacent artificial tooth with TempBond NE (Kerr Corporation, Orange, CA, USA).

Adjustment of interproximal distance and scanning procedure

Each adjacent restoration and inlay cavity was positioned as closely as possible using electronic calipers and secured with silicone impression material and a glue gun. After applying a rubber dam, the interproximal distance was adjusted to 0.6 mm, 0.8 mm, and 1.0 mm using electronic calipers. Digital scans were performed using the CEREC Prime AC (Figure 1). The typodont assembly was attached to a Thomas magnet for stability

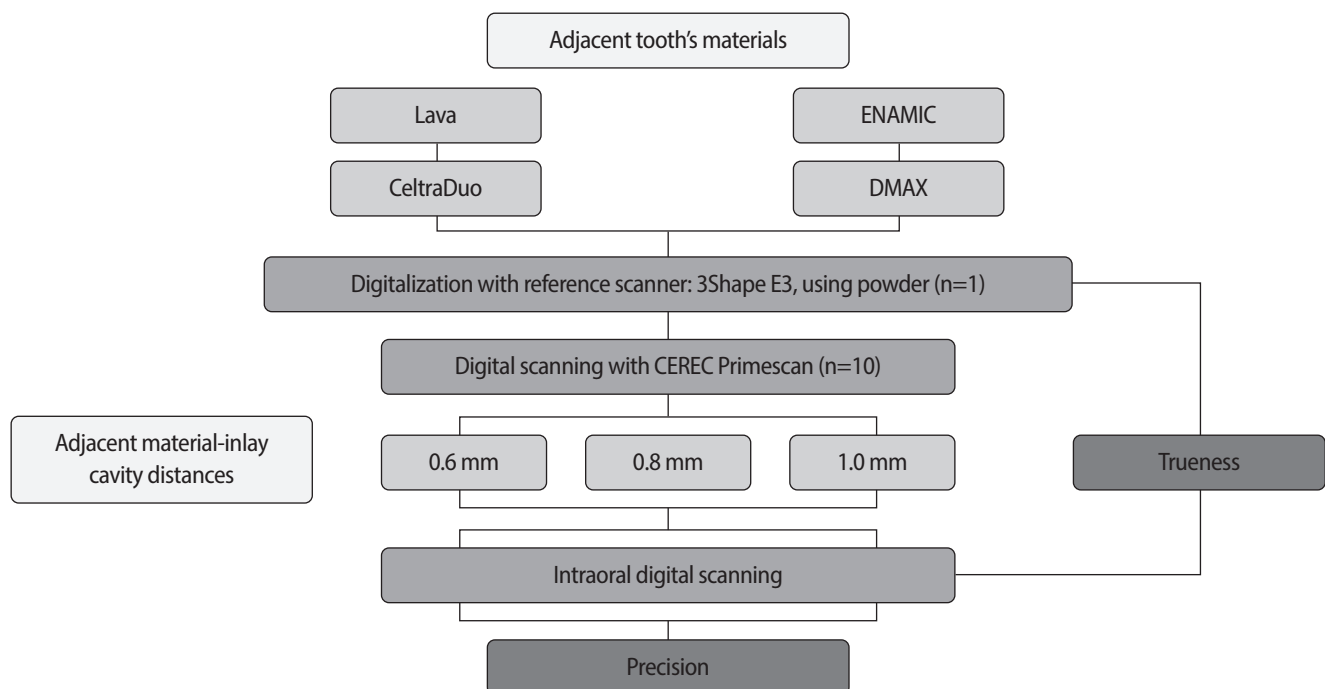


Figure 1. Experimental workflow showing the scanning procedure and variables. Four types of adjacent restorative materials (Lava, ENAMIC, Celtra Duo, DMAX) were tested with three interproximal distances (0.6 mm, 0.8 mm, 1.0 mm). Digital scanning was performed using a reference scanner (3Shape E3; 3Shape A/S, Copenhagen, Denmark) and intraoral scanner (CEREC Primescan; Dentsply Sirona, Charlotte, NC, USA). Trueness and precision were evaluated as outcome measures. Lava: 3M ESPE, St. Paul, MN, USA; ENAMIC: VITA Zahnfabrik, Bad Säckingen, Germany; Celtra Duo: Dentsply Sirona, Hanau, Germany; DMAX: DMAX, Daegu, Korea.

during scanning. Each experimental group was scanned 10 times according to the manufacturer's instructions. The scanned data were saved in STL file format.

Data analysis process

The accuracy of the scanned data from the experimental models was evaluated using 3D inspection software (GOM Inspect 2018; GOM GmbH). The trueness was analyzed by superimposing the reference and STL data using the initial and local best-fit alignment ($n = 10$). The scan data were quantified using mean deviation, and the mean maximum positive (+) and negative (–) deviations were calculated to assess the magnitude of the local trueness deviation. The precision was determined by superimposing the STL files of each experimental group with other data, consistently using initial alignment and local best-fit alignment for analysis ($n = 45$).

Statistical analysis

The experimental data were analyzed using statistical software (IBM SPSS Statistics, ver. 20.0; IBM Corp, Armonk, NY, USA). A two-way analysis of variance (ANOVA) was conducted to evaluate the effects of interproximal distance and adjacent tooth restorative material on trueness, mean maximum positive deviation, mean maximum negative deviation, and precision. In addition, a one-way ANOVA and Duncan's multiple comparison tests were used for *post hoc* analysis to assess the effects of each distance on each material and compare

the effects of each material at each distance. The significance level (α) was set to 0.05, and p -values ≤ 0.05 were considered significant.

RESULTS

Effect of the trueness, maximum deviation, minimum deviation, and precision according to distance and material

The restorative materials of adjacent teeth and the interproximal distance had significant effects on the trueness, mean maximum positive deviation, and mean maximum negative deviation, but there was no significant interaction effect between the two variables. In contrast, the materials and interproximal distance significantly affected the precision, and the interaction effect between the two variables was also significant (Table 1).

Comparisons between 0.6, 0.8, and 1.0 mm interproximal distances on the average deviation for trueness, precision, mean maximum positive deviation, and mean maximum negative deviation

1. Trueness

The range of the average trueness value ranged from $7.8 \pm 0.8 \mu\text{m}$ to $8.3 \pm 0.9 \mu\text{m}$. In addition, the 1.0 mm group showed significantly higher trueness than the 0.6 mm group ($p < 0.05$) (Table 2).

Table 1. Results of two-way ANOVA of parameters

Parameter	Source	df	SS	MS	F	p -value
Average deviation for trueness	Distance	2	4.0	2.0	4.0	0.02
	Material	3	18.7	6.2	12.5	<0.001
	Distance $\times$ Material	6	0.9	0.1	0.3	0.938
Maximum positive deviation	Distance	2	549.6	274.8	6.1	0.003
	Material	3	653.5	217.8	4.8	0.004
	Distance $\times$ Material	6	251.6	41.9	0.9	0.48
Maximum negative deviation	Distance	2	4,381.2	2,190.6	17.0	<0.001
	Material	3	1,322.9	441.0	3.4	0.02
	Distance $\times$ Material	6	1,523.2	253.9	2.0	0.077
Average deviation for precision	Distance	2	19.7	9.8	23.7	<0.001
	Material	3	72.9	24.3	58.5	<0.001
	Distance $\times$ Material	6	35.1	5.9	14.1	<0.001

ANOVA, analysis of variance; df, degree of freedom; SS, sum of squares; MS, mean squares.

Table 2. Comparisons between 0.6-mm, 0.8-mm, 1.0-mm interproximal distances for average deviation for trueness, mean maximum deviations, and precision (μm)

Distance (mm)	Average deviation for trueness	Maximum positive deviation	Maximum negative deviation	Average deviation for precision
0.6	8.3 ± 0.9^A	45.6 ± 8.8^A	32.0 ± 12.6^A	3.4 ± 1.0^A
0.8	8.2 ± 0.7^{AB}	43.5 ± 7.2^A	24.8 ± 12.7^B	2.9 ± 0.5^B
1.0	7.8 ± 0.8^B	40.4 ± 4.4^B	17.2 ± 10.5^C	3.1 ± 0.7^C

Values are presented as mean $\pm$ standard deviation.

Different superscript letters within same column indicate statistical difference between interproximal distances by Duncan multiple comparison test ($p < 0.05$).

2. Mean maximum positive deviation

The maximum positive deviation ranged from $45.6 \pm 8.8 \mu\text{m}$ to $40.4 \pm 4.4 \mu\text{m}$. The 0.6 mm group showed a significantly higher deviation than the 1.0 mm group ($p < 0.05$).

3. Mean maximum negative deviation

The maximum negative deviation was $32.0 \pm 12.6 \mu\text{m}$, $24.8 \pm 12.7 \mu\text{m}$, and $17.2 \pm 10.5 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively, with a significant decrease as the distance increased ($p < 0.05$).

4. Precision

The mean deviation of precision at 0.6 mm, 0.8 mm, and 1.0 mm was $3.4 \pm 1.0 \mu\text{m}$, $2.9 \pm 0.5 \mu\text{m}$, and $3.1 \pm 0.7 \mu\text{m}$, respectively, showing significant differences between each distance ($p < 0.05$). The lowest mean deviation was observed at 0.8 mm.

Comparisons between the adjacent materials for the average deviation for trueness, precision, mean maximum positive deviation, and mean maximum negative deviation

1. Trueness

The average deviation of trueness for each material ranged from $7.9 \pm 0.5 \mu\text{m}$ to $8.6 \pm 0.7 \mu\text{m}$. Celtra Duo showed the lowest trueness deviation, indicating the highest trueness, followed in order by increasing trueness deviation by Lava, DMAX, and ENAMIC. A significant difference was observed between Celtra Duo, Lava, and DMAX, ENAMIC ($p < 0.05$) (Table 3).

2. Mean maximum positive deviation

Celtra Duo showed the lowest maximum positive deviation, followed in ascending order by Lava, ENAMIC, and DMAX. No significant difference was noted between

Celtra Duo and Lava ($p > 0.05$). On the other hand, Celtra Duo showed a significant difference compared to ENAMIC and DMAX ($p < 0.05$). A significant difference was observed between Lava and DMAX ($p < 0.05$).

3. Mean maximum negative deviation

DMAX showed the lowest maximum negative deviation, followed in ascending order by ENAMIC, Celtra Duo, and Lava. No significant difference was observed between DMAX and ENAMIC ($p > 0.05$). Nevertheless, DMAX showed a significant difference compared to Lava and Celtra Duo ($p < 0.05$).

4. Precision

ENAMIC showed the lowest precision value, indicating the highest precision, followed by Lava, Celtra Duo, and DMAX in the ascending order of precision deviation. ENAMIC showed a significant difference from the other materials (Lava, Celtra Duo, and DMAX) ($p < 0.05$). Lava also showed a statistically significant difference from Celtra Duo and DMAX ($p < 0.05$). No significant difference was observed between Celtra Duo and DMAX ($p > 0.05$).

Comparisons of trueness, mean maximum deviations, and precision across different materials and interproximal distances

1. Trueness

Lava and Celtra Duo showed relatively high trueness at all distances. Lava showed a mean deviation of trueness of $8.0 \pm 0.3 \mu\text{m}$ at 0.6 mm and 0.8 mm, with a slight decrease to $7.5 \pm 0.6 \mu\text{m}$ at 1.0 mm. Celtra Duo showed a consistent mean deviation of trueness of $7.8 \pm 0.7 \mu\text{m}$ and $7.8 \pm 0.4 \mu\text{m}$ at 0.6 mm and 0.8 mm, respectively, with a further reduction to $7.3 \pm 0.4 \mu\text{m}$ at 1.0 mm, which was lower than that of Lava. Both materials

Table 3. Comparisons between materials for average deviation for trueness, mean maximum deviations, and precision (μm)

Material	Average deviation for trueness	Maximum positive deviation	Maximum negative deviation	Average deviation for precision
Lava	7.9 ± 0.5^A	42.3 ± 4.5^{AB}	28.7 ± 14.1^A	2.9 ± 0.5^A
ENAMIC	8.6 ± 0.7^B	44.1 ± 3.8^{BC}	22.7 ± 8.0^{AB}	2.6 ± 0.4^B
Celtra Duo	7.6 ± 0.5^A	39.9 ± 3.9^A	27.0 ± 18.9^A	3.5 ± 0.8^C
DMAX	8.4 ± 1.0^B	46.3 ± 12.1^C	20.3 ± 8.0^B	3.5 ± 1.0^C

Values are presented as mean $\pm$ standard deviation.

Different superscript letters within the same column indicate statistical difference between materials by Duncan multiple comparison test ($p < 0.05$). Lava: 3M ESPE, St. Paul, MN, USA; ENAMIC: VITA Zahnfabrik, Bad Säckingen, Germany; Celtra Duo: Dentsply Sirona, Hanau, Germany; DMAX: DMAX, Daegu, Korea.

Table 4. Comparisons of trueness, mean maximum deviations, and precision across different materials and interproximal distances (μm)

Parameter	Distance (mm)	Lava	ENAMIC	Celtra Duo	DMAX
Average deviation for trueness	0.6	8.0 ± 0.3^{Aa}	8.9 ± 0.5^{Ba}	7.8 ± 0.7^{Aa}	8.6 ± 1.3^{ABa}
	0.8	8.0 ± 0.3^{ABa}	8.6 ± 0.9^{Ba}	7.8 ± 0.4^{Aa}	8.4 ± 0.9^{ABa}
	1.0	7.5 ± 0.6^{Ab}	8.3 ± 0.6^{Ba}	7.3 ± 0.4^{Ab}	8.3 ± 0.8^{Ba}
Maximum positive deviation	0.6	44.9 ± 4.3^{ABa}	45.7 ± 3.6^{ABa}	41.0 ± 4.0^{Aa}	50.6 ± 15.4^{Ba}
	0.8	42.1 ± 3.0^{ABab}	44.2 ± 4.8^{ABa}	39.7 ± 3.0^{Aa}	48.1 ± 12.0^{Ba}
	1.0	40.0 ± 5.1^{Ab}	42.3 ± 2.1^{Aa}	39.0 ± 4.7^{Aa}	40.1 ± 4.9^{Aa}
Maximum negative deviation	0.6	38.4 ± 13.5^{Aa}	27.2 ± 8.5^{Aa}	34.4 ± 17.9^{Aa}	28.1 ± 4.3^{Aa}
	0.8	23.8 ± 1.9^{ABb}	25.3 ± 1.5^{ABa}	33.2 ± 21.8^{Aa}	16.7 ± 7.7^{Bb}
	1.0	23.8 ± 17.2^{Ab}	15.7 ± 6.9^{ABb}	13.3 ± 6.4^{Bb}	16.1 ± 5.3^{ABa}
Average deviation for precision	0.6	3.1 ± 0.7^{Aa}	2.6 ± 0.3^{Ba}	4.0 ± 1.0^{Ca}	3.8 ± 1.2^{Ca}
	0.8	2.7 ± 0.4^{Ab}	2.9 ± 0.3^{BCb}	2.8 ± 0.4^{ABb}	3.1 ± 0.7^{Cb}
	1.0	2.9 ± 0.3^{Aab}	2.4 ± 0.2^{Bc}	3.7 ± 0.6^{Cc}	3.4 ± 0.8^{Dab}

Values are presented as mean $\pm$ standard deviation.

Different capital superscript letters within the same row indicate statistically significant differences between materials ($p < 0.05$) while different lowercase superscript letters within the same column indicate statistically significant differences across distance by Duncan multiple comparison test ($p < 0.05$).

Lava: 3M ESPE, St. Paul, MN, USA; ENAMIC: VITA Zahnfabrik, Bad Säckingen, Germany; Celtra Duo: Dentsply Sirona, Hanau, Germany; DMAX: DMAX, Daegu, Korea.

showed a decrease in the mean deviation of trueness as the distance increased, with a statistically significant difference observed at 1.0 mm ($p < 0.05$). In contrast, ENAMIC and DMAX showed relatively lower trueness. ENAMIC exhibited a mean deviation of trueness of $8.9 \pm 0.5 \mu\text{m}$, $8.6 \pm 0.9 \mu\text{m}$, and $8.3 \pm 0.6 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively, showing a gradual decrease with increasing distance. DMAX recorded a similar mean deviation of trueness to ENAMIC, with values of $8.6 \pm 1.3 \mu\text{m}$, $8.4 \pm 0.9 \mu\text{m}$, and $8.3 \pm 0.8 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. Both materials showed a decreasing trend in the mean deviation of trueness as the distance increased, but the difference was not significant ($p > 0.05$) (Table 4).

2. Mean maximum positive deviation

Celtra Duo recorded consistently low mean maximum

positive deviation at all distances, with values of $41.0 \pm 4.0 \mu\text{m}$, $39.7 \pm 3.0 \mu\text{m}$, and $39.0 \pm 4.7 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively, showing a decreasing trend as the distance was increased. Lava showed a mean maximum positive deviation of $44.9 \pm 4.3 \mu\text{m}$ at 0.6 mm, decreasing to $42.1 \pm 3.0 \mu\text{m}$ and $40.0 \pm 5.1 \mu\text{m}$ at 0.8 mm and 1.0 mm, respectively. Both materials exhibited a decrease in the mean maximum positive deviation as the distance increased, with Celtra Duo showing lower values than Lava, but the difference was not significant ($p > 0.05$). ENAMIC recorded a mean maximum positive deviation, with $45.7 \pm 3.6 \mu\text{m}$ at 0.6 mm, decreasing to $44.2 \pm 4.8 \mu\text{m}$ and $42.3 \pm 2.1 \mu\text{m}$ at 0.8 mm and 1.0 mm, respectively. DMAX showed the highest mean maximum positive deviation, with $50.6 \pm 15.4 \mu\text{m}$ at 0.6 mm, decreasing slightly to $48.1 \pm 12.0 \mu\text{m}$ at 0.8 mm and decreasing significantly to $40.1 \pm 4.9 \mu\text{m}$ at 1.0 mm.

3. Mean maximum negative deviation

Celtra Duo also showed a decreasing trend in the mean maximum negative deviation as the distance increased. It recorded a mean maximum negative deviation of $34.4 \pm 17.9 \mu\text{m}$ at 0.6 mm, which decreased significantly to $13.3 \pm 6.4 \mu\text{m}$ at 1.0 mm, the lowest value among the materials. Lava exhibited a mean maximum negative deviation of $38.4 \pm 13.5 \mu\text{m}$ at 0.6 mm, decreasing to $23.8 \pm 1.9 \mu\text{m}$ and $23.8 \pm 17.2 \mu\text{m}$ at 0.8 mm and 1.0 mm, respectively, showing a similar decreasing trend to that of Celtra Duo. ENAMIC recorded a mean maximum negative deviation of $27.2 \pm 8.5 \mu\text{m}$ at 0.6 mm, which decreased to $25.3 \pm 1.5 \mu\text{m}$ at 0.8 mm and further to $15.7 \pm 6.9 \mu\text{m}$ at 1.0 mm. DMAX showed a mean maximum negative deviation of $28.1 \pm 4.3 \mu\text{m}$ at 0.6 mm, which decreased sharply to $16.7 \pm 7.7 \mu\text{m}$ at 0.8 mm and remained at a similar level of $16.1 \pm 5.3 \mu\text{m}$ at 1.0 mm.

4. Precision

ENAMIC showed a precision of $2.6 \pm 0.3 \mu\text{m}$ at 0.6 mm, which increased to $2.9 \pm 0.3 \mu\text{m}$ at 0.8 mm and then decreased to $2.4 \pm 0.2 \mu\text{m}$ at 1.0 mm, the lowest precision value observed. Lava recorded a mean deviation of precision of $3.1 \pm 0.7 \mu\text{m}$ at 0.6 mm, which decreased to $2.7 \pm 0.4 \mu\text{m}$ at 0.8 mm, followed by a slight increase to $2.9 \pm 0.3 \mu\text{m}$ at 1.0 mm. Celtra Duo had the highest precision at 0.6 mm ($4.0 \pm 1.0 \mu\text{m}$), which decreased to $2.8 \pm 0.4 \mu\text{m}$ at 0.8 mm but increased again to $3.7 \pm 0.6 \mu\text{m}$ at 1.0 mm. DMAX recorded a high deviation of $3.8 \pm 1.2 \mu\text{m}$ at 0.6 mm and showed an increase to $3.1 \pm 0.7 \mu\text{m}$ and $3.4 \pm 0.8 \mu\text{m}$ at 0.8 mm and 1.0 mm, respectively.

DISCUSSION

This study evaluated the effects of adjacent restorative materials (3M Lava Ultimate, VITA ENAMIC, Celtra Duo, DMAX CAD/CAM Blocks) and the distance between the inlay cavity and the adjacent restoration (0.6 mm, 0.8 mm, and 1.0 mm) on the impression accuracy of inlay cavities using an intraoral scanner. Four indicators were measured: mean deviation of trueness, mean maximum positive deviation, mean maximum negative deviation, and mean deviation of precision. The restorative material and the distance had significant effects on each of the four indicators, whereas the interaction between the

material and distance had a significant effect only on the mean deviation of precision. These findings suggest that the type of material and the interproximal distance may independently influence trueness and precision. Consequently, the first hypothesis, which posited that adjacent restorative materials would have no significant effect on accuracy, and the second hypothesis, asserting that interproximal distance would not significantly impact accuracy, were rejected. In contrast, the third hypothesis, suggesting that there would be no effect of the interaction between material and distance on accuracy, was partially rejected. Although the interaction between adjacent material type and interproximal distance was not statistically significant in most comparisons, a potential interaction effect was hypothesized based on the optical characteristics of CAD/CAM materials. In clinical situations, the impact of limited interproximal spacing on scan accuracy may not be independent of the adjacent material's surface properties. For instance, highly translucent or reflective materials such as zirconia or lithium disilicate could intensify light scattering or internal reflection when the interproximal space is narrow. These optical disturbances may exacerbate scanning challenges in confined areas, where limited scanner angulation and reduced light penetration already compromise image acquisition. Therefore, the third null hypothesis was included to explore the potential for such compounded effects, even under controlled *in vitro* conditions. While the statistical results did not confirm a significant interaction in most parameters, the rationale for its inclusion was grounded in optical considerations relevant to intraoral scanning in restricted clinical environments.

A dental phantom head model was used to replicate the intraoral environment, providing conditions that closely simulate the clinical setting to enhance the clinical applicability of the results. In addition, the distances between the adjacent restoration and the inlay cavity were set to 0.6 mm, 0.8 mm, and 1.0 mm to assess the effects of interproximal distance on the trueness and precision under various clinical situations. The 0.6-mm-simulated conditions in which the adjacent tooth and restoration are in close proximity allow an evaluation of potential limitations in scanning and possible data omission in narrow spaces. In contrast,

the 1.0 mm distance represented a relatively wider interproximal gap, enabling clear recognition of the cavity margins without interference from adjacent restorations [11]. By setting these various interproximal distance conditions, this study could assess the differences in accuracy at each distance and, more precisely, determine how these changes influence trueness and precision.

These results revealed variations in scanning accuracy based on these distance conditions. The mean deviation of trueness was significantly higher at 0.6 mm ($8.3 \pm 0.9 \mu\text{m}$) compared to that observed at 1.0 mm ($7.8 \pm 0.8 \mu\text{m}$) ($p < 0.05$), indicating a tendency for lower trueness at narrower distances. In addition, the mean deviation of precision was highest at 0.6 mm ($3.4 \pm 1.0 \mu\text{m}$), whereas a lower value of $3.1 \pm 0.7 \mu\text{m}$ was observed at 1.0 mm. Hence, a narrow interproximal distance may adversely affect the trueness and precision.

When scanning an inlay cavity with an intraoral scanner, the restorative material of the adjacent tooth may affect the accuracy of digital impression acquisition. This is because the restorative material of the adjacent tooth can alter the reflection and absorption of the scanner light, making it more difficult to distinguish the cavity margins [14,15]. Consequently, there is a potential for distortion in the shape or depth of the cavity, or even for data omission in certain areas. In addition, the gloss and texture of the restorative surface can also affect the data acquisition of the scanner. According to some reports, highly glossy surfaces may reflect excessive light, potentially reducing the scanner's ability to capture fine details and thus affecting the accurate reproduction of the cavity's form [16,17].

ENAMIC has a hybrid structure, combining a ceramic network with a resin matrix, giving it an opaque quality and high reflectivity [18]. The consistent reflection from the surface of ENAMIC enables the scanner to collect precise, repetitive data, contributing to its superior precision. In the experimental results, ENAMIC showed the best performance in precision, with deviations of $2.6 \pm 0.3 \mu\text{m}$, $2.9 \pm 0.3 \mu\text{m}$, and $2.4 \pm 0.2 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. In contrast, the mean deviation of trueness for ENAMIC was lowest at $8.9 \pm 0.5 \mu\text{m}$, $8.6 \pm 0.9 \mu\text{m}$, and $8.3 \pm 0.6 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. This phenomenon may be related to light scattering or multiple reflections within

the material due to differences in refractive indices and optical properties of the ceramic and resin components, which can hinder accurate recognition of boundary and depth information, as suggested in previous studies [2,19].

Celtra Duo is composed of lithium silicate ceramic, characterized by high optical translucency and a fine crystalline structure. This structure allows the scanner to reflect some light from the surface while transmitting part of it internally, facilitating accurate recognition of the depth and internal structures [20]. The experimental results showed that the mean deviation of trueness for Celtra Duo was $7.8 \pm 0.7 \mu\text{m}$, $7.8 \pm 0.4 \mu\text{m}$, and $7.3 \pm 0.4 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. On the other hand, the precision was relatively lower, with deviations of $4.0 \pm 1.0 \mu\text{m}$, $2.8 \pm 0.4 \mu\text{m}$, and $3.7 \pm 0.6 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. This suggests that although the optical translucency and reflectivity of Celtra Duo are advantageous for achieving high trueness, the multiple scattering pathways and inconsistent boundary recognition contribute to its lower precision.

Lava is a resin-based composite material composed of nano-ceramic particles, enabling uniform reflection and transmission of light and contributing to enhanced trueness performance. In this study, Lava showed consistent trueness deviations of $8.0 \pm 0.3 \mu\text{m}$ at 0.6 mm and 0.8 mm, with a reduction to $7.5 \pm 0.6 \mu\text{m}$ at 1.0 mm. The precision deviations were $3.1 \pm 0.7 \mu\text{m}$, $2.7 \pm 0.4 \mu\text{m}$, and $2.9 \pm 0.3 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively, showing stability, but it was slightly higher than that of ENAMIC. The relatively low optical heterogeneity and consistent light pathways in Lava contributed significantly to its improved trueness performance [21].

DMAX is a zirconia material with high opacity and strong reflectivity that exhibits relatively large deviations in both trueness and precision. The trueness deviations for DMAX were recorded as $8.6 \pm 1.3 \mu\text{m}$, $8.4 \pm 0.9 \mu\text{m}$, and $8.3 \pm 0.8 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively, while precision deviations were $3.8 \pm 1.2 \mu\text{m}$, $3.1 \pm 0.7 \mu\text{m}$, and $3.4 \pm 0.8 \mu\text{m}$ at 0.6 mm, 0.8 mm, and 1.0 mm, respectively. These results may be explained by the high opacity of zirconia, which limits light penetration and causes most light to be reflected from the surface, as reported in previous studies [15,22]. Consequently, this limits the ability of the scanner to recognize the

boundary and depth data, which likely contributed to the observed lower trueness and precision.

Celtra Duo consistently showed superior performance in trueness and maximum positive deviation, maintaining low trueness deviations across all distances and showing minimal impact from the changes in distance. In addition, Celtra Duo exhibited stable and low maximum positive deviation values at all distances, with its best performance in the maximum negative deviation observed at a distance of 1.0 mm. In contrast, ENAMIC showed the best performance in precision, displaying consistently low precision deviations with minimal effect from distance changes. DMAX performed well in the maximum negative deviation at a distance of 0.8 mm but displayed relatively higher deviations at other distances. Lava showed moderate overall performance, but it recorded the highest deviation in maximum negative deviation at 0.6 mm.

The lithium silicate ceramic Celtra Duo showed high trueness, while the hybrid ceramic ENAMIC exhibited high precision, suggesting that these two materials possess distinct advantages. In addition, when the interproximal distance was close (0.6 mm), there was an increased likelihood of data omission or distortion, indicating the need for caution in clinical settings when scanning narrow interproximal spaces for CAD-CAM restoration.

These findings suggest that adjacent restorative material and interproximal distance should be considered carefully during digital impression acquisition using CAD/CAM systems. In particular, a narrow interproximal distance (0.6 mm) increases the likelihood of data omission or distortion, highlighting the need to enlarge the interproximal space or apply supplementary protocols to enhance the scanning accuracy under these conditions. In contrast, most materials provide stable scanning accuracy when the interproximal distance is wider at 1.0 mm, making them clinically suitable [13,14]. This study provides foundational guidance for dental clinicians using CAD/CAM systems in selecting optimal adjacent restorative materials and conditions for digital impressions.

This study was conducted as an *in vitro* experiment in a laboratory setting, which may differ in some respects from clinical conditions. For example, in the oral cavity,

factors such as saliva, limited mouth opening, patient movement, and refractive index differences between teeth and gingiva can affect the scanning accuracy. Furthermore, this study did not consider factors such as the gloss and surface roughness (polishing, glazing, and roughness) of each material and used only one type of scanner, limiting the evaluation of how these factors may affect the scanner accuracy. Therefore, future research should incorporate these clinical elements to assess the scanner accuracy and propose methods to improve the accuracy of digital impressions under various clinical conditions.

CONCLUSIONS

Under the conditions of this study, the adjacent restorative material and interproximal distance individually had significant effects on the accuracy variables, trueness, and precision in the digital impression of the inlay cavity. On the other hand, the interaction between the two factors significantly affected only precision. The lithium silicate ceramic Celtra Duo and the hybrid ceramic ENAMIC each showed high trueness and precision, respectively, with trueness and precision being higher at 1.0 mm than at 0.6 mm.

CONFLICT OF INTEREST

Sung-Ae Son is an Editorial Advisory Board member and Deog-Gyu Seo is an Scientific Advisory Board member of *Restorative Dentistry and Endodontics* and these authors were not involved in the peer-review or editorial process of this article. The authors declare no other conflicts of interest.

FUNDING/SUPPORT

This work was supported by a 2-year Research Grant of Pusan National University.

AUTHOR CONTRIBUTIONS

Conceptualization, Funding acquisition, Project administration, Supervision: Park JK. Data curation, Investigation, Software, Visualization: Lee SY. Formal analysis, Resources, Validation: Son SA. Methodology: Kim JH, Seo DG. Writing - original draft: Lee SY. Writing - review & editing: Kim JH, Park JK. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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