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ORIGINAL ARTICLE

Effect of CAD-CAM restorative materials and scanning aid conditions on the accuracy and time efficiency of intraoral scans

Jun-Ho Cho DDS, MSD, PhD[1] | **Gülce Çakmak DDS, PhD**[2] | **Burak Yilmaz DDS, PhD**[2,3,4] | **Hyung-In Yoon DDS, MSD, PhD**[1,2]

[1]Department of Prosthodontics, Seoul National University School of Dentistry and Dental Research Institute, Seoul, Republic of Korea

[2]Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

[3]Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland

[4]Division of Restorative and Prosthetic Dentistry, The Ohio State University, Columbus, Ohio, USA

Correspondence
Hyung-In Yoon, DDS, MSD, PhD, Department of Prosthodontics, Seoul National University School of Dentistry and Dental Research Institute, 101, Daehak-ro, Jongro-gu, Seoul, 03080, Republic of Korea.
Email: drhiy226@snu.ac.kr

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Abstract

Purpose: This in vitro study aimed to evaluate the effects of restorative materials and scanning aid conditions on the accuracy and time efficiency of intraoral scans.

Materials and Methods: Identical anatomic contour crowns were fabricated using the following materials: hybrid ceramic, 3 mol% yttria-stabilized tetragonal zirconia, 4 mol% yttria-partially stabilized zirconia, 5 mol% yttria-partially stabilized zirconia, cobalt–chromium (Co–Cr), resin, lithium disilicate, and feldspathic ceramic. The models were digitized and analyzed for accuracy ($n = 10$) under three scanning aid conditions (powder-based, liquid-based, and none). Additionally, the effect of metal restorations on the scan accuracy of other crowns was investigated. The scan time for complete arches was also recorded. One-way analysis of variance, Welch analysis of variance, and post-hoc comparison or independent t-tests were used for trueness analysis, and the F-test was used to examine precision ($\alpha = 0.05$).

Results: Significant differences were observed in the trueness of the different restorative materials under the no-scanning aid condition ($P < 0.05$). In contrast, no statistically significant difference among the groups was observed with the powder- or liquid-based scanning aid. For each restorative material, the no-scanning aid condition showed significantly lower trueness than that with powder- or liquid-based scanning aids. The presence of a Co–Cr crown did not affect the trueness of other restorations in the arch. The scan time efficiency significantly increased on applying a powder- or liquid-based scanning aid.

Conclusions: Using a scanning aid was effective to improve the scan accuracy of the tested restorative materials and scan time efficiency. Applying scanning aids to existing intraoral restorations can help improve prosthesis quality and reduce the need for clinical adjustment at the occlusal or proximal contacts.

KEYWORDS
accuracy, CAD-CAM, intraoral scan, restorative materials, scanning aid

In prosthetic dentistry, the preparation of digital impressions with an intraoral scanner (IOS) has simplified clinical and laboratory procedures, increased time efficiency, minimized patient discomfort, and allowed better communication with patients and dental technicians, thereby substituting conventional physical impressions.[1–9] Although scan accuracy has improved with the rapid development of technology, there are factors that can affect the accuracy of digital impressions obtained with an IOS, such as scan range, scanning strategy, software or hardware version, operator competence, ambient light, and ambient temperature.[9–28] Therefore, the scan accuracy in different intraoral situations remains controversial and needs to be studied.[29–34]

Patients, especially older adults, tend to use various types of restorative materials along the edentulous sites.[35,36] Various restorative materials with different refractive indices and translucency parameters may influence the accuracy of the IOS.[10,24,37–40] Glossy or shiny metal surfaces are highly reflective and cause over-exposure during scanning, making it difficult to acquire surface information.[41,42] Highly translucent restorations have been reported to decrease scan accuracy.[39,40] Applying scanning aids to the surface of the

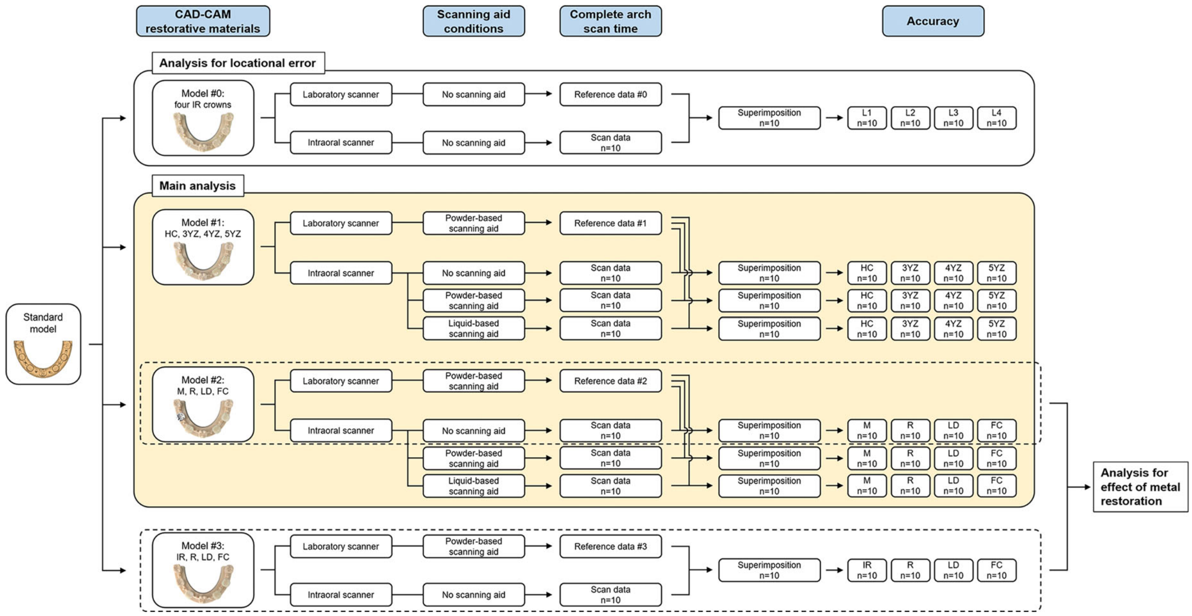

FIGURE 1 Flow chart of study design. L1, first index; L2, second index; L3, third index; L4, fourth index; HC, hybrid ceramic; 3YZ, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 4YZ, 4 mol% yttria-partially stabilized zirconia; 5YZ, 5 mol% yttria-partially stabilized zirconia; M, cobalt-chromium; R, resin; LD, lithium disilicate glass-ceramic; FC, feldspathic ceramic; IR, integrated resin.

restoration could help eliminate the effect of the reflective properties of the restoration material and improve scan accuracy.[39,40] However, applying a powder-based scanning aid (PSA) with a spray may be technique sensitive and could cause errors in applying an uneven thickness of the coating layer.[24,43] Applying a liquid-based scanning aid (LSA) with a brush could be relatively less technique sensitive, enable a targeted application to specific areas, and result in a more uniform coating layer on the applied surface.[44] However, no controlled studies have simultaneously evaluated the effects of various restorative materials and scanning aids on the scan accuracy of IOSs.

Therefore, the purpose of this in vitro study was to investigate the effect of eight computer-aided design and computer-aided manufacturing (CAD-CAM) restorative materials (hybrid ceramic [HC], 3 mol% yttria-stabilized tetragonal zirconia polycrystal [3Y-TZP, 3YZ], 4 mol% yttria-partially stabilized zirconia [4Y-PSZ, 4YZ], 5 mol% yttria-partially stabilized zirconia [5Y-PSZ, 5YZ], printable cobalt-chromium [Co–Cr, M], printable resin [R], lithium disilicate glass-ceramic [LD], and feldspathic ceramic [FC]) and scanning aid conditions (powder-based, liquid-based, and none) on the scan accuracy and time efficiency of an IOS. The null hypotheses were that restorative materials and scanning aid conditions do not affect the accuracy (first null hypothesis) and time efficiency (second hypothesis) of the intraoral scan.

MATERIALS AND METHODS

The study design is summarized in a flow chart (Figure 1). An acrylic resin mandibular left first molar with a tooth preparation design (A21A Series; Nissin, Kyoto, Japan) was digitized using a laboratory scanner (T710; Medit, Seoul, Korea). An arch-shaped model with seven identical teeth (three reference and four index) generated from the tooth scan data was designed using CAD software (Exocad Dental CAD; Exocad GmbH, Darmstadt, Germany). An anatomic contour crown (1.5-mm occlusal surface thickness, 1.0-mm axial wall thickness, and 0.3-mm margin thickness) was designed on each reference tooth located in the middle and at both ends of the arch, and stored as a standard tessellation language (STL) format. By adding various geometric shapes on the external surfaces of the crowns on three reference teeth, a three-dimensional (3D) arch-shaped standard model was developed.

To identify the bias that might occur due to the allocated location of restorations, the anatomic contour crowns with identical designs were added on four index teeth of the standard model. A resin model (model #0, Figure 2a) with four integrated resin (IR) crowns at different locations (L1, first index; L2, second index; L3, third index; L4, fourth index) was fabricated using a digital light processing (DLP)-based printer with a light intensity of 7.50 mW/cm2 and 385-nm wavelength (Asiga UV Max; Asiga, Sydney, Australia) and printable resin (DentaMODEL; Asiga), following the manufacturer's instructions. Model #0 was digitized by using the laboratory scanner and a triangulation-based IOS (i700 wireless; Medit). The operating software programs were as follows: Medit Link version 2.6.4, Medit Scan for Clinics version 1.8.4, and Medit Scan for Labs version 1.3.3. A board-certified prosthodontist with 6-years of experience in IOS performed all scan procedures after calibrating the scanners before each scan.[45] Digitizing with IOS was performed without scanning aids on occlusal surfaces, from terminal

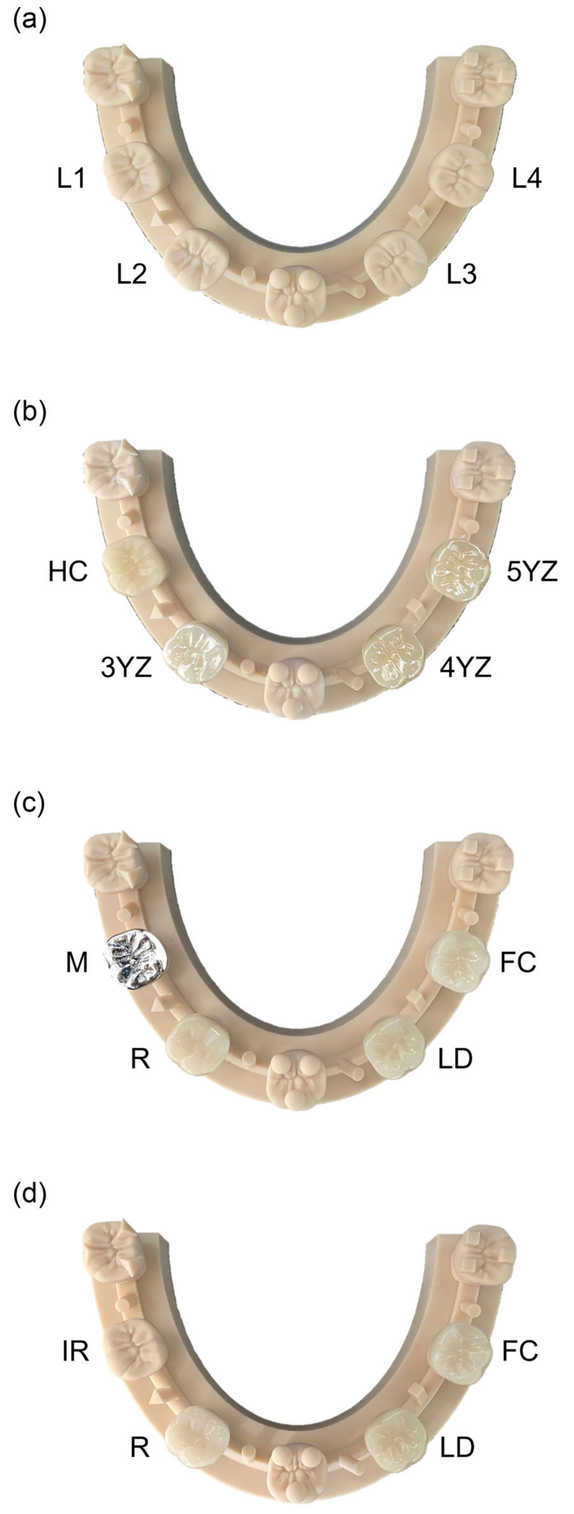

FIGURE 2 Experimental models in the present study. (a) Standard model with four integrated resin crowns (model #0). (b) Standard model comprising HC, 3YZ, 4YZ, and 5YZ crowns (model #1). (c) Standard model comprising M, R, LD, and FC crowns (model #2). (d) Standard model comprising IR, R, LD, and FC crowns (model #3). L1, first index; L2, second index; L3, third index; L4, fourth index; HC, hybrid ceramic; 3YZ, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 4YZ, 4 mol% yttria-partially stabilized zirconia; 5YZ, 5 mol% yttria-partially stabilized zirconia; M, cobalt-chromium; R, resin; LD, lithium disilicate glass-ceramic; FC, feldspathic ceramic; IR, integrated resin.

teeth on the left toward the terminal teeth on the right, along the geometric shapes in the arch, and on smooth surfaces in a continuous manner with display mode and a reliability map to verify complete scanning.[46] The scan time was also recorded for each complete-arch scanning with the IOS. The scan data for model #0 with the laboratory scanner were used as reference data (reference data #0). For the 3D surface deviation analysis, the IOS data for model #0 (n = 10) were superimposed on reference data #0 using an inspection software program (Geomagic Control X; 3D Systems, Morrisville, NC). The external surfaces of the crowns on three reference teeth were set as references for the best-fit alignment, using an iterative closest point algorithm to minimize the distance between the point clouds. The external surface of each IR crown at four different locations (L1–L4) from each IOS data was compared with the surface of the corresponding crown from reference data #0, and the root-mean-square (RMS) value for each crown was calculated for accuracy. Trueness and precision were calculated as mean and standard deviation of RMS values, respectively.[47,48]

Two resin-based standard models (models #1 and #2) were fabricated using the DLP printer and printable resin. Using the pre-designed crown STL file, 8 identical anatomic contour crowns of different materials were fabricated following the manufacturer's instructions and were classified into 8 different groups: HC, 3YZ, 4YZ, 5YZ, M, R, LD, and FC (Table 1). In detail, the HC and FC crowns were fabricated using a five-axis milling machine (5X-300 Pro; Arum Dentistry, Daejeon, Korea). The 3YZ, 4YZ, and 5YZ crowns were fabricated by using the milling machine, followed by sintering at a final temperature of 1530°C with 2-h holding time in a furnace (PDF-1000; DentalMax, Seoul, Korea). The M crown was fabricated with Co–Cr alloy powder by using a selective laser melting-based printer (VP100; Profeta, Nanjing, China). The R crown was fabricated with printable resin by using the DLP printer. The printing parameters for both M and R crowns were set as 50-μm layer thickness. The LD crown was fabricated using a five-axis milling machine, followed by devitrification at a final temperature of 840°C and a 10-min holding time (Austromat 624; Dekema GmbH, Freilassing, Germany). Final surface treatment was performed by polishing all crowns: the 3YZ, 4YZ, 5YZ, LD, and FC crowns were treated with a polishing kit (NTI CeraGlaze, NTI-Kahla GmbH, Kahla, Germany), HC and R crowns with a Vita Enamic polishing set (VITA Zahnfabrik, Bad Säckingen, Germany), and M crowns with rubber wheels and cylinders (Dedeco Classic Dedeco Intl., New York, NY).[49,50] None of the crowns underwent glazing. These crowns were bonded on the index teeth of the resin-based standard models with translucent resin cement (RelyX U200 automix TR; 3 M ESPE, St Paul, MN, USA).

A set of standard models (#1 and #2) with the bonded CAD-CAM crowns (Figure 2b and c) was digitized with a laboratory scanner using a PSA (VITA Powder Scan Spray; VITA Zahnfabrik). The scan data were then used as reference data #1 and #2 for models #1 and #2, respectively. The models were subsequently scanned with the IOS under

TABLE 1 CAD-CAM restorative materials evaluated in this study.

Group	Material	Product name and manufacturer
HC	Hybrid ceramic	VITA Enamic 2M2-HT; VITA Zahnfabrik, Bad Säckingen, Germany
3YZ	3Y-TZP	Katana ML A2; Kuraray Noritake, Tokyo, Japan
4YZ	4Y-PSZ	Katana STML A2; Kuraray Noritake
5YZ	5Y-PSZ	Katana UTML A2; Kuraray Noritake
M	Co-Cr (printable)	CCM-15; High Dental Korea, Seoul, Korea
R	Resin (printable)	Tera Harz TC-80DP A2; Graphy, Seoul, Korea
LD	Lithium disilicate glass-ceramic	IPS e.max CAD A2-HT; Ivoclar Vivadent, Schaan, Liechtenstein
FC	Feldspathic ceramic	Vitablocs Mark II A2C; VITA Zahnfabrik

Abbreviations: CAD-CAM, computer-aided design and computer-aided manufacturing; 3Y-TZP, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 4Y-PSZ, 4 mol% yttria-partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria-partially stabilized zirconia.

three different conditions: PSA, LSA (Scan Cure; ODS Co., Incheon, Korea), and no scanning aids (NSA). According to the manufacturer's instructions, PSA was applied at a five-inch distance with a 45-degree angulation, and LSA was applied once with a brush. Scanning was conducted 10 times with the IOS under each scanning aid condition. The scan time was also recorded for each complete-arch scanning with the IOS. The models were thoroughly cleaned with steam to remove the applied scanning aids and air-dried between the conditions. For 3D surface deviation analysis, the 10 scans obtained with the IOS under each scanning aid condition were superimposed on the corresponding reference data #1 and #2 with the inspection software program. The external surfaces of three reference teeth of the models were set as references for the best-fit alignment based on the iterative closest point algorithm for each superimposition. The external surface of each crown from the IOS data was compared with the corresponding crown surface from reference data #1 and #2, and the RMS values for each crown under each scanning aid condition ($n = 10$) were calculated for accuracy.

To investigate the scan data noise that the reflective surface of the M crowns influences the scan data of other crowns of different materials on the arch, an additional model integrated with an ideal anatomic contour crown, replacing the location of the M crown in model #2, was designed and fabricated using the DLP printer and printable resin (model #3). Except for the IR crown, the R, LD, and FC crowns were fabricated and cemented on abutments as described above (Figure 2d). Digitizing with the IOS was performed under NSA conditions and the scan data were compared with those with M crown (model #2) under NSA conditions. Analyses of scan accuracy and time efficiency were performed as described (Figure 1).

Normality and equality of variances were assessed using the Shapiro-Wilk and Levene tests. Individual one-way analysis of variance, Welch analysis of variance, and independent t-tests were conducted, and a post-hoc pairwise comparison was adjusted using the Bonferroni and Dunnett T3 methods to evaluate the trueness data. An F-test with the Bonferroni method was used to examine data precision. All data analyses were performed using a statistical software program (IBM SPSS Statistics v27.0; IBM Corp., Armonk, NY, USA), and statistical significance was set at $P < 0.05$.

RESULTS

Analysis for locational error revealed no statistically significant difference among the locations in the arch model (L1 with 29.6 ± 9.0 μm; L2 with 22.1 ± 6.4 μm; L3 with 22.0 ± 7.2 μm; L4 with 28.2 ±16.1 μm, Figure 3), meaning the location of the restorations caused no significant bias.

An analysis of the influence of the restorative materials and scanning aid conditions on the scan accuracy of IOS is presented in Table 2 and Figure 4. Under the NSA conditions, the HC and 3YZ groups showed lower mean RMS values, whereas the M group showed the highest mean RMS value ($P < 0.05$). The mean RMS values of all groups, except the HC and 3YZ groups, exceeded the clinically acceptable limit of 50 μm for the CAD-CAM crown.[51–56] Under PSA and LSA conditions, no significant difference was observed among the materials. For each restorative material group, the NSA condition showed a significantly higher RMS value than the PSA or LSA condition ($P < 0.05$), except for the HC and 3YZ groups. In terms of scan data noise, the presence of the M crown, or its highly-reflective metal surface, did not significantly affect the IOS data accuracy of the other restorations in the same arch (Table 3).

Time efficiency analysis for complete-arch scanning revealed that applying a PSA or LSA to models #1 and #2 significantly reduced the scan time ($P < 0.05$) (Table 4). Under NSA conditions, the presence of an M crown significantly increased the scan time, but nevertheless remained insufficient for complete scanning of its highly-reflective metal surface ($P < 0.05$).

DISCUSSION

The first and second null hypotheses were rejected based on the results of the present study. CAD-CAM restorative

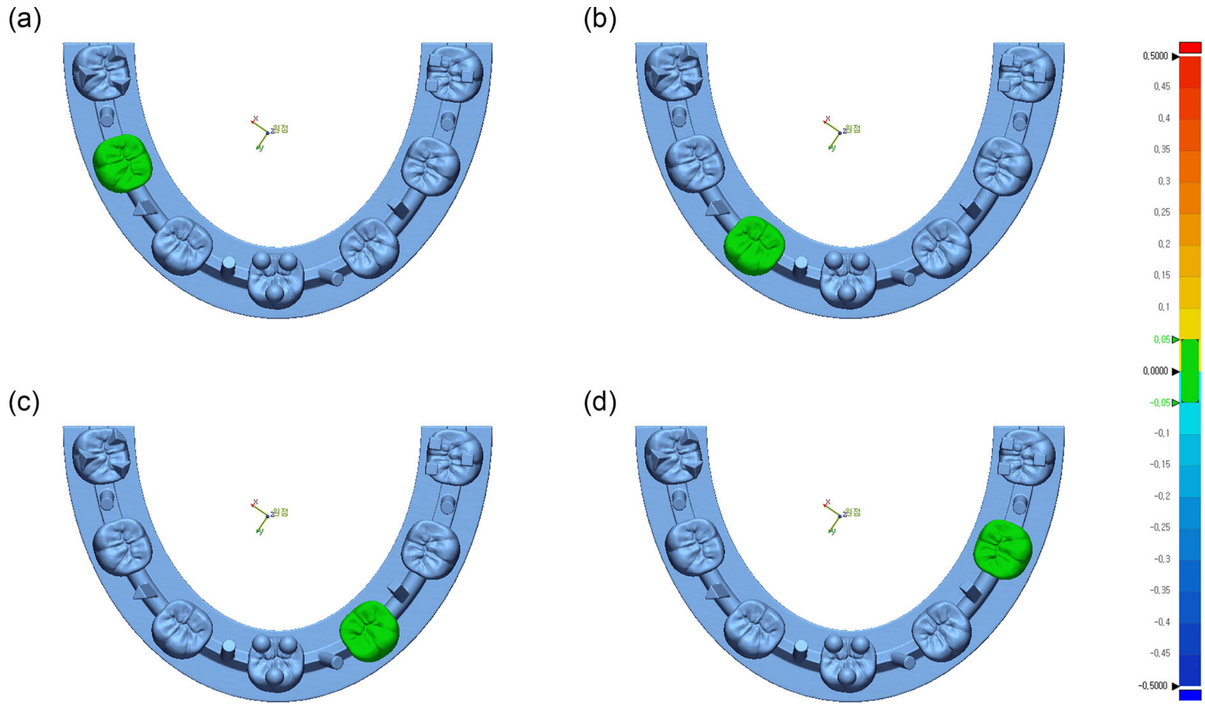

FIGURE 3 Color deviation maps of the anatomic contour crowns (integrated resin) in model #0 with no scanning aid. (a) L1, first index. (b) L2, second index. (c) L3, third index. (d) L4, fourth index. Nominal deviation was ±50 μm, and critical deviation was ±500 μm.

TABLE 2 Trueness ± precision (mean ± standard deviation of RMS, μm) for anatomic contour prostheses with eight CAD-CAM materials and under three scanning aid conditions.

	HC	3YZ	4YZ	5YZ	M	R	LD	FC
NSA	38.0 ± 10.8^{Aa}	29.6 ± 5.1^{Aa}	61.9 ± 12.0^{Bb}	70.2 ± 18.6^{Bb}	496.8 ± 172.3^{Bc}	74.6 ± 10.1^{Bb}	70.9 ± 6.7^{Bb}	77.3 ± 6.6^{Bb}
PSA	36.2 ± 15.4^{Aa}	33.7 ± 10.3^{Aa}	34.2 ± 12.1^{Aa}	34.9 ± 12.4^{Aa}	34.0 ± 11.9^{Aa}	30.2 ± 10.4^{Aa}	26.8 ± 14.2^{Aa}	32.8 ± 15.0^{Aa}
LSA	33.2 ± 10.2^{Aa}	31.8 ± 12.2^{Aa}	30.0 ± 7.3^{Aa}	33.3 ± 14.4^{Aa}	31.7 ± 10.9^{Aa}	32.9 ± 10.0^{Aa}	33.0 ± 9.1^{Aa}	29.9 ± 9.8^{Aa}

Abbreviations: RMS, root mean square; CAD-CAM, computer-aided design and computer-aided manufacturing; HC, hybrid ceramic; 3YZ, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 4YZ, 4 mol% yttria-partially stabilized zirconia; 5YZ, 5 mol% yttria-partially stabilized zirconia; M, Co–Cr alloy; R, printable resin; LD, lithium disilicate glass-ceramic; FC, feldspathic ceramic; NSA, no scanning aid; PSA, powder-based scanning aid; LSA, liquid-based scanning aid. Uppercase superscript letters indicate comparisons within each column. Lowercase superscript letters indicate comparisons within each row. Different letters indicate statistically significant differences $P < 0.05$.

TABLE 3 Effect of metal crowns on scan accuracy without scanning aid expressed in trueness ± precision (mean ± standard deviation of RMS, μm).

	IR	M	R	LD	FC
Model #2	–	$496.8 \pm$ s172.3^{b}	74.6 ± 10.1^{Aa}	70.9 ± 6.7^{Aa}	77.3 ± 6.6^{Aa}
Model #3	36.1 ± 13.8^{a}	–	66.9 ± 8.3^{Ab}	66.9 ± 12.6^{Ab}	69.6 ± 11.1^{Ab}

Abbreviations: RMS, root mean square; IR, integrated resin crown; M, Co–Cr alloy; R, printable resin; LD, lithium disilicate glass-ceramic; FC, feldspathic ceramic. Uppercase superscript letters indicate comparisons within each column. Lowercase superscript letters indicate comparisons within each row. Different letters indicate statistically significant differences $p < 0.05$.

materials and scanning aid conditions significantly affect the accuracy and time efficiency of intraoral scans. Under NSA conditions, the M crown had the highest mean RMS value. The highly reflective surface of the M crowns resulted in incomplete scanning, severe data noise, and delayed scan time. The translucent surfaces of the 4Y-PSZ, 5Y-PSZ, R, LD, and FC crowns also affected the scanning process. The HC and 3YZ crowns, which were less translucent, showed a lower mean RMS value and were easier to scan. The results of this study were similar to those of previous studies that evaluated the effect of different restorative materials on the scan accuracy of IOSs under no-scanning-aid conditions.[10,38,49,50] In contrast, applying a scanning aid set all tested crowns under even conditions for IOS scanning, with no significant difference in the mean RMS values of the crowns, and reduced the scan time. In a clinical situation, applying a

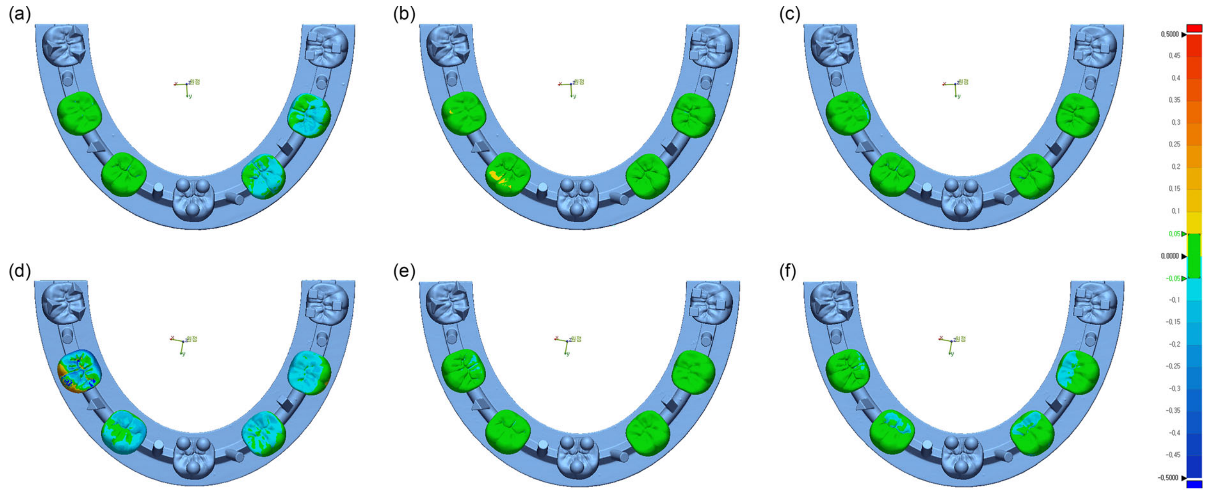

FIGURE 4 Color deviation maps of the anatomic contour crowns of model #1 (HC, 3YZ, 4YZ, and 5YZ, from left to right) (upper row) and model #2 (M, R, LD, and FP, from left to right) (lower row). (a) and (d): No scanning aid. (b) and (e): Powder-based scanning aid. (c) and (f): Liquid-based scanning aid. Nominal deviation was ± 50 μm, and critical deviation was ± 500 μm. HC, hybrid ceramic; 3YZ, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 4YZ, 4 mol% yttria-partially stabilized zirconia; 5YZ, 5 mol% yttria-partially stabilized zirconia; M, cobalt-chromium; R, resin; LD, lithium disilicate glass-ceramic; FC, feldspathic ceramic.

TABLE 4 Scan time (minutes) taken for complete-arch scanning with an intraoral scanner.

	Model #0	Model #1	Model #2	Model #3
NSA	6.7 ± 0.9^{a}	10.3 ± 0.9^{Bc}	12.8 ± 1.5^{Bd}	8.4 ± 1.0^{b}
PSA	–	7.2 ± 1.1^{Aa}	7.1 ± 1.0^{Aa}	–
LSA	–	7.1 ± 1.2^{Aa}	7.4 ± 1.1^{Aa}	–

Abbreviation: NSA, no scanning aid; PSA, powder-based scanning aid; LSA, liquid-based scanning aid. Uppercase superscripts indicate comparisons within each column. Lowercase superscript letters indicate comparisons within each row. Different letters indicate statistically significant differences $P < 0.05$.

scanning aid can help increase IOS accuracy for translucent or reflective CAD-CAM restorative materials in the oral cavity. Definitive prostheses fabricated using inaccurate scan data can result in an inappropriate occlusal or proximal contact, necessitating additional effort and time for adjustment. The scan data of translucent materials without scanning aids exhibited negative surface deviations; thus, indirect restorations fabricated using scan data without scanning aids could have an excessive occlusal or proximal contact when translucent restorations are present on the opposing or adjacent dentition. Scan time needs to be considered to achieve sufficient quality of the intraoral scan. A prolonged time may be associated with disturbances in scanning, possibly due to unnecessary jaw or tongue movements and erratic data accumulation. Reducing the time by applying scanning aids on the reflective or translucent surface may be helpful to obtain accurate IOS data in less chair time.

For the standard model, a complete-arch shape was designed to simulate the dental arch and identical mandibular left first molars were arranged to avoid errors due to differences in shapes. Complete-arch scanning with an IOS may result in intrinsic stitching errors larger than those during partial-arch scanning, possibly due to morphologic differences between anterior and posterior regions as well as the scanning area.[10–12,20,23,33] However, no locational bias was identified in the present study. To minimize stitching errors and improve registration of captured images, various geometric features were attached to the molar crowns on three reference teeth. With our model, the crowns on four index teeth could be evaluated simultaneously for each scanning procedure. The model was also designed to have a space between adjacent teeth to diminish the effect of adjacent teeth and enable complete scanning of the entire proximal surface.

The scan data inaccuracy caused by amalgam and gold surfaces was reported as negligible,[57] however, scanning the highly-reflective surface of the metal-based crown was still challenging, as the M crowns in this study could not be completely scanned without any scanning aid. Furthermore, several translucent restorative materials, such as the 4YZ, 5YZ, R, LD, and FC crowns, showed relatively high RMS values for IOS scans with no scanning aid; nevertheless, they could be completely digitized in more scanning time. High translucency of restorative material can decrease the accuracy of IOS data as subsurface-scattered light can interfere with the direct reflection of the light from the material surface.[39,40] Further studies are necessary to assess the effect of the optical properties of various materials on scan accuracy.

No significant difference was observed between the PSA and LSA conditions in this study, although PSA application could be technique sensitive and its thickness may introduce some bias.[24,43] The data obtained by using a laboratory scanner with no scanning aid could not serve as a reference due to imperfect quality, and reference data #1 and #2 were acquired after applying PSA. The effort by a trained prosthodontist to apply a minimum amount and uniform coating layer of PSA may have helped minimize errors, which may be smaller in magnitude than the surface deviations caused by highly translucent or reflective restorations.

This study has some limitations. The intraoral scanner used in this study was based on triangulation technology, and using scanners with different scan technologies may result in different scan accuracies. In addition, the intrinsic stitching and rendering algorithm may affect the accuracy and elapsed time in complete-arch scanning. A further study on IOS based on different technologies is required. Second, all the crowns made of different materials were polished but not glazed for experimental uniformity and reproducibility. Surface finish of restorations may result in different outcomes in IOS scan accuracy, which warrants further study.

CONCLUSIONS

Based on these findings, the accuracy and time efficiency of intraoral scans for CAD-CAM restorative materials can be improved by using scanning aids (powder- or liquid-based). A scanning aid may be applied to the existing intraoral restorations to improve prosthesis quality and reduce the need for clinical adjustments, such as those at occlusal or proximal contacts.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

ORCID

Jun-Ho Cho DDS, MSD, PhD https://orcid.org/0000-0002-1416-7915
Gülce Çakmak DDS, PhD https://orcid.org/0000-0003-1751-9207
Burak Yilmaz DDS, PhD https://orcid.org/0000-0002-7101-363X
Hyung-In Yoon DDS, MSD, PhD https://orcid.org/0000-0002-9597-6342

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