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Original Article

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

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Translucency;
Scanning aid

Abstract *Background/purpose:* Subsurface scattering from translucent material would affect the digital scans. This study aimed to evaluate the effect of translucency of ceramic restorative materials and scanning aid conditions on the accuracy of intraoral scans.
Materials and methods: Identical anatomic contour crowns with ten ceramic restorative materials were fabricated: five zirconia, three lithium disilicate glass-ceramic, and two leucite reinforced glass-ceramic. The models with ceramic crowns were digitized with an intraoral scanner (IOS) and analyzed for accuracy (n = 10) with and without a scanning aid. Scan time efficiency was recorded. Square-shaped specimens with 1.0-mm thickness were fabricated with the same materials, and translucency parameter (TP) values were measured. One-way ANOVA, Welch ANOVA, and a post-hoc pairwise comparison or independent *t*-test were used for trueness and time analysis, and the F-test was used to examine the precision ($\alpha = 0.05$). Pearson correlation test was conducted.
Results: Significant differences were revealed for trueness with no scanning aid condition and for TP values ($P < 0.05$). In contrast, no statistically significant differences were observed for trueness with a scanning aid. A strong correlation ($r = 0.854$, $P < 0.01$) between TP value and trueness with no scanning aid was revealed. By applying a scanning aid, trueness was improved and scan time efficiency significantly increased ($P < 0.05$).
Conclusion: The translucency of ceramic restorative materials negatively affects the accuracy of IOS scan without a scanning aid; however, the scan accuracy and time efficiency of IOS scanning for ceramic restorations can be improved by applying scanning aid, and prostheses with high quality without unnecessary labor can be produced.

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Introduction

With the development of digital and manufacturing technologies, intraoral digital scanning has been widely used to fabricate dental prostheses due to reduced time and better patient comfort than conventional impression taking.[1—4] For the quality of prostheses, a marginal discrepancy of restorations with computer-aided design and computer-aided manufacturing (CAD-CAM) workflow has been reported to be compatible with that of conventional workflow.[5,6] However, unlike conventional impression taking, digital scan uses light to acquire information and encounters difficulties associated with the optical phenomenon, such as subsurface scattering, surface characteristics, and ambient light conditions.[7—9]

Nowadays, zirconia, lithium disilicate glass-ceramic, and leucite-reinforced glass-ceramic are widely used dental ceramics for metal-free ceramic restorations, and they feature translucency and improved strength.[10] With the development of digital technology, these ceramics are commercially manufactured for milling in CAD-CAM workflow as well as for conventional workflow. Translucency is the primary factor that dental restorations achieve esthetics looking similar to natural teeth.[11] When light encounters the surface of materials, it is reflected, refracted, and absorbed. Subsurface scattering is an optical phenomenon that occurs when light penetrates the surface and is scattered within the object, and then the majority exits the surface. Subsurface scattering allows restoration materials to have translucency and look similar to natural teeth.[7,12,13] However, subsurface-scattered light would interfere with the light that was directly reflected on the surface; thus, it would influence the accuracy of an intraoral scanner (IOS).[7] In practice, it is hard to scan thoroughly the translucent materials with IOS without any scanning aid. A previous study with feldspathic ceramic reported that higher translucency led to morphological changes and lower scanning accuracy.[7] Dental ceramics have been developed to meet the demand for esthetics, having high translucency, thus, substantial subsurface scattering.

Trueness and precision are used to assess the accuracy of IOS.[14,15] Trueness is defined as the closeness of agreement between the experimental results and an accepted reference value, and precision is defined as the closeness of agreement between the experimental results. Short scan time with IOS helps to improve the accuracy, especially in a clinical situation with the presence of saliva, the need for soft tissue management, and patient movement.[16] Thus, considering time efficiency would be meaningful regarding the accuracy of IOS.

The purpose of this in vitro study was to investigate the effect of the translucency of CAD-CAM ceramic restorative materials (zirconia, lithium disilicate glass-ceramic, and leucite reinforced glass-ceramic) and scanning aid conditions (liquid-based and none) on the scan accuracy and time efficiency of an IOS. The research hypotheses were that the translucency of ceramic materials would affect the scan accuracy of the IOS and that scanning aid conditions would affect the time efficiency of the IOS.

Materials and methods

Specimen preparation

A maxillary typodont (TRN 406; Nissin Dental, Kyoto, Japan) with an acrylic resin maxillary right first premolar with tooth preparation design (A50-141; Nissin Dental) was digited with a dental laboratory scanner (T710; Medit, Seoul, Korea). The region from the maxillary right canine to the second premolar was selected, and the gingiva level was adjusted to expose the tooth preparation margin with a computer-aided design (CAD) software program (exocad Dental CAD; exocad GmbH, Darmstadt, Germany), then ten models were fabricated with a DLP printer (Asiga UV Max; Asiga, Sydney, Australia) and printable resin (DentaMODEL; Asiga).

The ideal anatomic contour crown for the maxillary right first premolar was virtually designed (as a crown STL file). Ten ceramic groups were established: zirconia (Z1, Z2, Z3, Z4, and Z5), lithium disilicate glass-ceramic (LD1, LD2, and LD3), and leucite reinforced glass-ceramic (L1 and L2) (Table 1). An ideal anatomic contour crown for each group was fabricated using the crown STL file. The zirconia crowns were fabricated with a five-axis milling machine (5X-300 Pro; Arum Dentistry, Daejeon, Korea), followed by

Table 1 Ceramic restorative materials tested in this study.

Group	Material	Product Name and Manufacturer
Z1	3 mol% yttria-stabilized tetragonal zirconia polycrystal	Katana ML A2; Noritake, Aichi, Japan
Z2	4 mol% yttria-partially stabilized zirconia	Katana STML A2; Noritake
Z3	5 mol% yttria-partially stabilized zirconia	Katana UTML A2; Noritake
Z4	3 mol% yttria-stabilized tetragonal zirconia polycrystal	Lava Plus; 3 M ESPE, St Paul, MN, USA
Z5	5 mol% yttria-partially stabilized zirconia	Lava Esthetic A2; 3 M ESPE
LD1	Lithium disilicate glass-ceramic	IPS e.max CAD A2-LT; Ivoclar Vivadent, Schaan, Liechtenstein
LD2	Lithium disilicate glass-ceramic	IPS e.max CAD A2-MT; Ivoclar Vivadent
LD3	Lithium disilicate glass-ceramic	IPS e.max CAD A2-HT; Ivoclar Vivadent
L1	Leucite reinforced glass-ceramic	IPS Empress CAD A2-LT; Ivoclar Vivadent
L2	Leucite reinforced glass-ceramic	IPS Empress CAD A2-HT; Ivoclar Vivadent
Control	Resin (printable)	DentaMODEL; Asiga, Sydney, Australia

Z1 to Z5: zirconia groups, LD1 to LD3: lithium disilicate glass-ceramic groups, L1 and L2: leucite reinforced glass-ceramic groups.

sintering (final sintering temperature of 1530 °C and 2-h holding time) (PDF-1000; DentalMax, Seoul, Korea). Lithium disilicate glass-ceramic crowns were fabricated with the five-axis milling machine (5X-300 Pro; Arum Dentistry) followed by devitrification (final temperature of 840 °C and 10-min holding time) (AUSTROMAT 624; Dekema Dental-Keramiköfen GmbH, Freilassing, Germany). Leucite reinforced glass-ceramic crowns were fabricated with the five-axis milling machine (5X-300 Pro; Arum Dentistry). All crowns were polished (NTI CeraGlaze polishing kit; NTI-Kahla GmbH, Kahla, Germany) for final surface treatment. Glazing was not performed. The crowns were cemented on abutments of printed models with translucent resin cement (RelyX U200 automix TR; 3 M ESPE, St Paul, MN, USA), and excess cement was carefully and thoroughly removed. Ten experimental models (one model for each group) were completed (Fig. 1A).

As a control group, a modified model, which has an integrated resin crown on the maxillary right first premolar abutment, was designed with the CAD software program (exocad Dental CAD; exocad GmbH) and fabricated with the DLP printer (Asiga UV Max; Asiga) and printable resin (DentaMODEL; Asiga) (Fig. 1B).

Scan accuracy and time efficiency

For each group, the model was digitized with the dental laboratory scanner (T710; Medit) after applying a liquid-based scanning aid (Scan Cure; ODS Co., Incheon, Korea) on the cemented crown. The scan data with the laboratory scanner were used as reference data for superimposition and accuracy analysis. The model was also digitized ten times with an IOS (i700 wireless; Medit) for two scanning aid conditions: without a scanning aid (NSA) and with a liquid-based scanning aid (Scan Cure; ODS Co.) (SA) on the cemented crown. The IOS in this study uses a triangulation technique and features three-dimensional (3D)-in-motion video technology and 3D full-color streaming capture utilizing an LED light source. Scanning with IOS was performed in sequence: occlusal surfaces from second premolar to canine, the labial surface of canine to buccal surface of second premolar, and palatal surfaces from second premolar to canine. IOS scan data were used as experimental data. Scan time with IOS for each model for two scanning aid conditions was recorded. The dental laboratory scanner and IOS were calibrated before every scan. A highly experienced

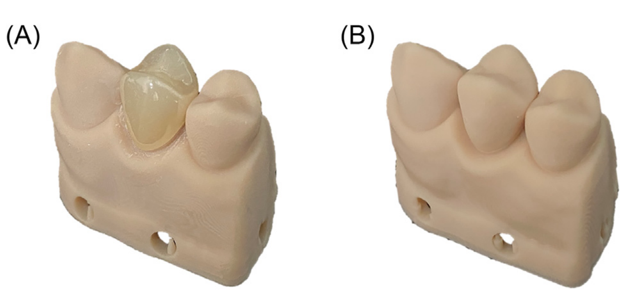

Figure 1 (A) Representative experimental model with zirconia crown (Lava Esthetic). (B) Modified model with integrated resin crown on the maxillary right first premolar abutment as control group.

prosthodontist performed all scans. For 3D surface deviation analysis, ten scan data with IOS for each scanning aid condition were superimposed on reference data with a 3D inspection software program (Geomagic Control X; 3D Systems, Morrisville, NC, USA). The external surfaces of the maxillary right canine and second premolar were set as references for superimposition, and the best-fit alignment algorithm superimposed reference data and IOS scan data. The external surfaces of crowns for the maxillary right first premolar from each IOS scan data and reference data were three-dimensionally compared, and root-mean-square (RMS) values were calculated using the following formula:

$$\mathrm{RMS} = \frac{\sqrt{\sum_{i=1}^{n}(X_{1,i} - X_{2,i})^2}}{\sqrt{n}}$$

where n is the total number of measuring points, $X_{1,i}$ is the measuring point i on the reference data, and $X_{2,i}$ is the measuring point i on the IOS scan data. For accuracy analysis, trueness and precision were calculated as the mean and standard deviation of ten RMS values, respectively. A higher RMS value refers to a more significant deviation of IOS scan data from reference data and lower trueness. The 3D surface deviation color maps for each IOS scan were generated with a nominal deviation of ±50 μm with green color and a critical deviation of ±500 μm with red and blue colors.

Translucency

For each ceramic group, a thin square-shaped specimen (10.0 mm × 10.0 mm × 1.0 mm) was fabricated for translucency analysis. The same apparatuses for crown fabrication were used. For zirconia groups, specimens were fabricated with the five-axis milling machine (5X-300 Pro; Arum Dentistry), followed by sintering (PDF-1000; DentalMax). For lithium disilicate glass-ceramic groups, specimens were fabricated with the five-axis milling machine (5X-300 Pro; Arum Dentistry), followed by devitrification (AUSTROMAT 624; Dekema Dental-Keramiköfen GmbH). For leucite reinforced glass-ceramic groups, specimens were fabricated with the five-axis milling machine (5X-300 Pro; Arum Dentistry). Specimens were ground (SPL-15 Grind X; Okamoto, Tokyo, Japan) and then polished (NTI CeraGlaze polishing kit; NTI-Kahla GmbH) for one side, and then the same procedures were conducted on the opposite side, to the final dimension with 1.0-mm thickness. A spectrophotometer (CM-700d; Konica Minolta, Tokyo, Japan) was used to measure the translucency parameter (TP). The International Commission on Illumination (CIE) L^*, $a*$, and $b*$ color coordinates of each specimen were measured. For each specimen, $L*$, $a*$, and $b*$ values were measured against a black background (CM-A101B, Konica Minolta, $L* = 4.86$, $a* = -1.06$, and $b* = -1.23$) and a white background (CM-A101W, Konica Minolta, $L* = 93.81$, $a* = -0.20$, and $b* = 3.03$). TP value of the specimen was calculated by the color difference between values against a black and a white background, calculated by the following equation:

$$\mathrm{TP} = \sqrt{(L_B{}^* - L_W{}^*)^2 + (a_B{}^* - a_W{}^*)^2 + (b_B{}^* - b_W{}^*)^2}$$

Table 2 Accuracy (trueness ± precision (mean ± standard deviation of root-mean-square, μm)) of scanning with intraoral scanner for anatomic contour ceramic crowns with two scanning aid conditions, and translucency parameter (TP) of 1.0-mm thickness square-shaped specimens with ceramic restorative materials.

		Z1	Z2	Z3	Z4
Accuracy	NSA	44.0 ± 5.0^{A}	65.6 ± 9.8^{B}	73.8 ± 7.8^{BC}	70.9 ± 4.4^{B}
	SA	23.4 ± 3.2^{A}	24.4 ± 6.1^{A}	25.5 ± 5.8^{A}	21.9 ± 2.7^{A}
TP		13.0 ± 0.21^{A}	14.6 ± 0.07^{C}	15.7 ± 0.35^{D}	13.3 ± 0.09^{A}
		Z5	**LD1**	**LD2**	**LD3**
Accuracy	NSA	75.0 ± 3.4^{B}	82.4 ± 2.4^{C}	83.4 ± 2.3^{C}	104.9 ± 3.2^{E}
	SA	25.6 ± 3.5^{A}	23.4 ± 5.5^{A}	21.2 ± 6.0^{A}	24.7 ± 3.6^{A}
TP		13.8 ± 0.08^{B}	17.8 ± 0.15^{E}	19.8 ± 0.02^{G}	21.9 ± 0.08^{H}

		L1	L2	Control
Accuracy	NSA	82.1 ± 3.4^{C}	89.8 ± 2.8^{D}	39.8 ± 3.6^{A}
	SA	22.3 ± 3.7^{A}	25.2 ± 3.3^{A}	23.8 ± 3.3^{A}
TP		18.8 ± 0.05^{F}	21.7 ± 0.05^{H}	–

Uppercase superscripts are for comparison within each row, and different alphabet indicates statistically significant difference $P < 0.05$. NSA: no scanning aid, SA: liquid-based scanning aid, TP: translucency parameter, Z1 to Z5: zirconia groups specified in Table 1, LD1 to LD3: lithium disilicate glass-ceramic groups specified in Table 1, L1 and L2: leucite reinforced glass-ceramic groups specified in Table 1.

where subscript B refers to the color coordinates measured against the black background and subscript W refers to color coordinates measured against the white background.[17,18]

Statistical analysis

Descriptive statistics using means and standard deviations, calculated from the measured RMS values, TP values, and scan time, were analyzed. The normality and equality of variances were assessed by using the Shapiro-Wilk and Levene tests. Individual one-way ANOVA, Welch ANOVA, and independent *t*-test were conducted, and a post-hoc pairwise comparison was adjusted using Bonferroni and Dunnett T3 method to evaluate the trueness and time efficiency of IOS scan and TP values ($\alpha = 0.05$). The F-test with Bonferroni method was used to examine the precision of the IOS scan ($\alpha = 0.05$). The Pearson correlation test was performed to investigate the correlation between TP value and mean RMS values of the IOS scan without scanning aid. All data analyses were performed using a statistical software program (IBM SPSS Statistics v27.0; IBM Corp., Armonk, NY, USA), and statistical significance was denoted by $P < 0.05$.

Results

Scan accuracy

The accuracy of scanning with IOS for anatomic contour crowns with ceramic restorative materials and two scanning aid conditions was summarized (Table 2) and visualized in 3D color deviation maps (Fig. 2). For ceramic crowns with NSA condition, LD3 group showed the lowest trueness, and Z1 group showed the highest trueness ($P < 0.05$). The 3D color deviation maps showed light blue colors over substantial areas. For ceramic crowns with SA condition, no statistically significant difference was observed among the groups, and the 3D color deviation maps showed green colors over most areas. Improved trueness of scanning with IOS by applying a scanning aid was observed.

The result for the control group (integrated resin crown) was also presented (Table 2 and Fig. 3). Because the reference data for ten ceramic groups were obtained after applying scanning aid, the control group was used to evaluate the errors caused by reference data obtained with scanning aid. By the independent *t*-test, integrated resin crown with NSA condition showed significantly higher RMS values than with SA condition ($P < 0.05$), meaning that applying scanning aid to establish reference data would have caused increased RMS values for NSA condition due to inevitable scanning aid thickness. The 3D color deviation map for integrated resin crown with NSA condition showed light blue color, meaning negative deviation, in some areas. Therefore, the independent *t*-test for scan accuracy between two scanning aid conditions (NSA and SA) was not conducted for ten ceramic groups.

Translucency

TP values of 1.0-mm thickness square-shaped specimens with ceramic restorative materials were summarized (Table 2). LD3 group showed the highest TP value, and Z1 group showed the lowest TP value ($P < 0.05$).

Correlation between translucency and trueness of intraoral scan

A scatter plot relating TP values of ceramic restorative materials and the trueness of scanning with the intraoral scanner for anatomic ceramic crowns without scanning aid was presented (Fig. 4). Pearson correlation test revealed a strong positive correlation ($r = 0.854$, $P < 0.01$) between TP value and mean RMS values of IOS scan without scanning aid, meaning higher translucency leads to lower trueness.

Time efficiency

Scan time with IOS for each model with two scanning aid conditions was summarized (Fig. 5). Under NSA and SA

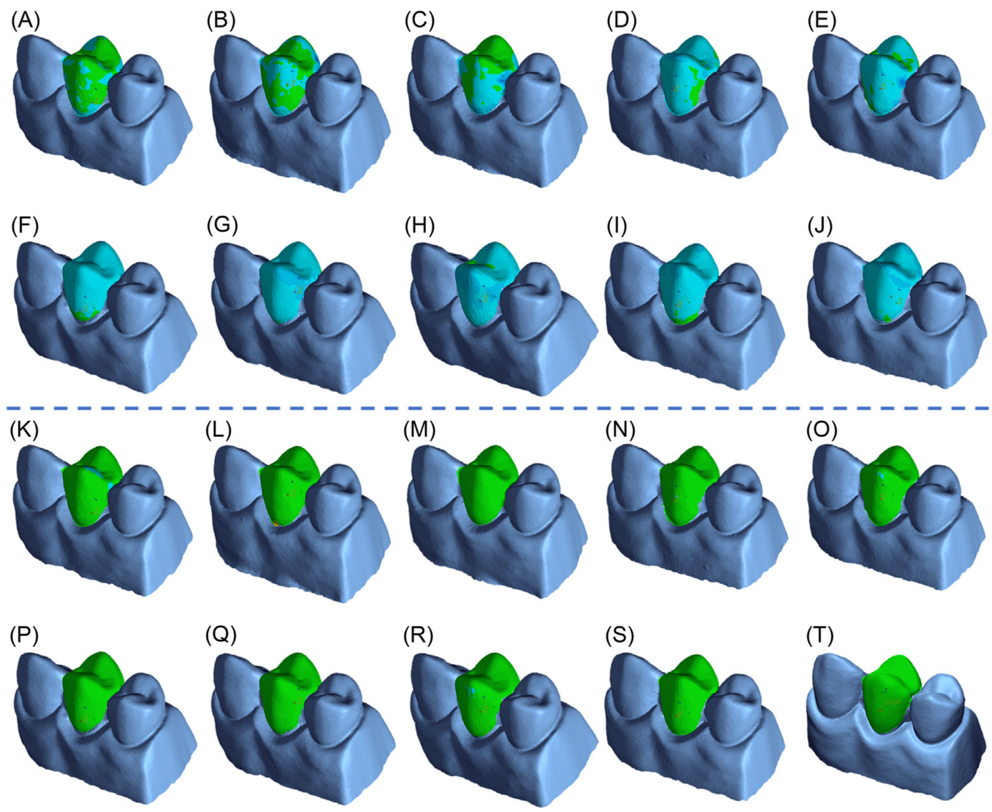

Figure 2 Three-dimensional color deviation maps for anatomic contour ceramic crowns without scanning aid (first and second rows: A to J) and with liquid-based scanning aid (third and fourth rows: K to T). (A, K) Z1. (B, L) Z2. (C, M) Z3. (D, N) Z4. (E, O) Z5. (F, P) LD1. (G, Q) LD2. (H, R) LD3. (I, S) L1. (J, T) L2. Z1 to Z5: zirconia groups specified in Table 1, LD1 to LD3: lithium disilicate glass-ceramic groups specified in Table 1, L1 and L2: leucite reinforced glass-ceramic groups specified in Table 1.

conditions, no statistically significant difference was observed among ceramic material groups. For all ceramic groups, applying the scanning aid significantly reduced the scan time ($P < 0.05$).

Discussion

Based on the results of this study, the translucency of ceramic restorative affected the scan accuracy of IOS, and scanning aid conditions significantly affected time efficiency, supporting the research hypotheses. In addition, improvement in the trueness of IOS scan with a scanning aid was observed in 3D color deviation maps.

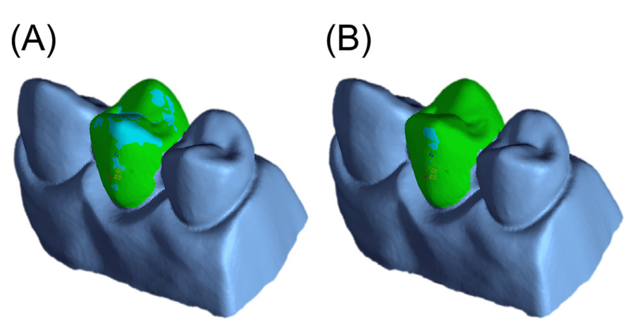

Figure 3 Three-dimensional color deviation maps for integrated resin crown (control group) with scanning aid conditions. (A) No scanning aid. (B) Liquid-based scanning aid.

Higher translucency was correlated with lower trueness for scanning with IOS. By the 3D color deviation map, surface areas obtained by IOS without scanning aid showed negative deviation, meaning inward deviation or smaller crown scan data. If the opposing or adjacent tooth of the abutment is restored with translucent material, a fabricated crown for the abutment would have heavy occlusal or proximal contact, sometimes requiring enormous

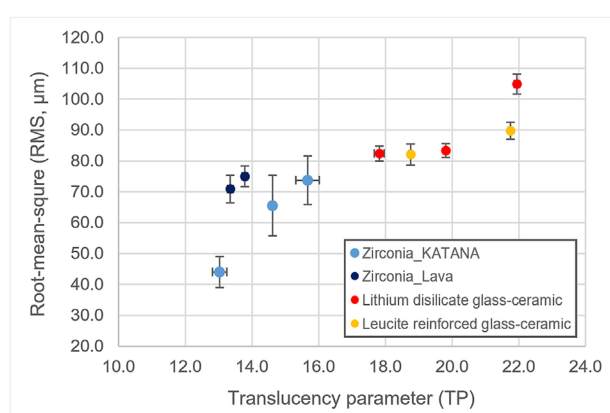

Figure 4 Scatter plot relating translucency parameter (TP) values of ceramic restorative materials and trueness (mean of root-mean-square (RMS), µm) of scanning with intraoral scanner for anatomic ceramic crowns without scanning aid.

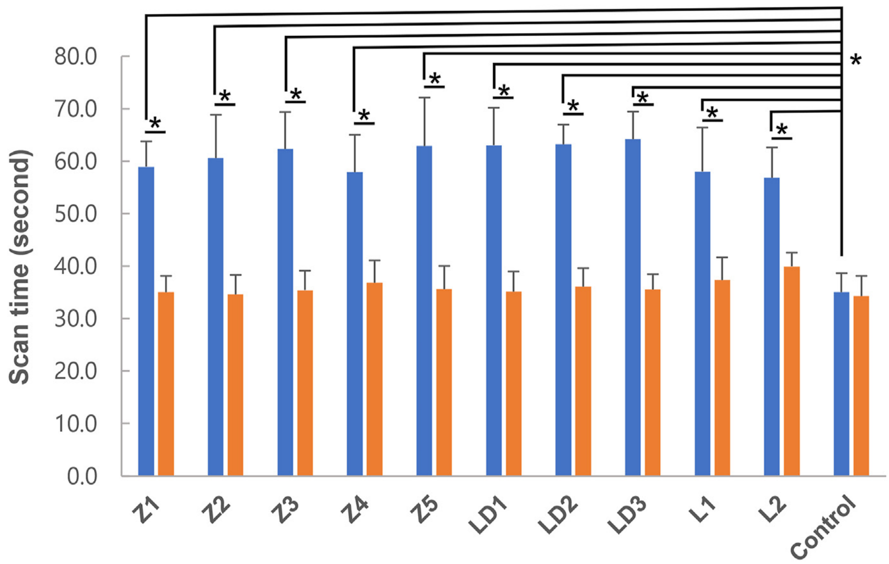

Figure 5 Scan time (second) taken for scanning with intraoral scanner with two scanning aid conditions: without scanning aid (blue bar) and with liquid-based scanning aid (orange bar). *: statistical significance ($P < 0.05$). Z1 to Z5: zirconia groups specified in Table 1, LD1 to LD3: lithium disilicate glass-ceramic groups specified in Table 1, L1 and L2: leucite reinforced glass-ceramic groups specified in Table 1.

adjustment with increased clinical chair time. Even though the scan accuracy of IOS does not solely depend on the translucency of material, the accuracy and time efficiency of IOS for translucent ceramic restoration could be improved by applying a scanning aid, and superior prostheses for abutment could be fabricated.

In this study, reference data were established by a dental laboratory scanner after applying liquid-based scanning aid. Despite the effort to apply the thinnest and most uniform layer of liquid-based scanning aid by a trained prosthodontist, errors due to the thickness of the scanning aid were detected. Nevertheless, the magnitude of this type of error was much smaller than the errors caused by the high translucency or optical properties of ceramic materials. Scanning with a dental laboratory scanner without a scanning aid led to poor quality data due to the optical properties of ceramic materials and could not be served as reference data; thus, alternative reference data with a scanning aid was used. For this reason, using an industrial scanner without a scanning aid to get reference data would be considered to improve reliability in further studies.

Translucency would be affected by surface finishing, such as glazing and polishing, material thickness, and material brand.[19–22] Ceramic crowns and specimens in the present study were all polished as a surface treatment to exclude the effect of different surface treatments. For zirconia, it was reported that polishing as a surface finishing is recommended to reduce antagonist enamel wear and maintains the strength of zirconia restoration.[23] Future studies with different surface treatments and different thickness of restoration would result deeper insight.

TP values for tested 1.0-mm thickness ceramic specimens ranged from 13.0 to 21.9. Zirconia groups (Z1 to Z5) showed TP values from 13.0 to 15.7, and glass-ceramic groups (lithium disilicate glass-ceramic (LD1 to LD3) and leucite-reinforced glass-ceramic (L1 and L2)) showed higher TP values from 17.8 to 21.7. The translucency of glass-ceramic is affected by crystalline content within the glass matrix, the difference in refractive indices between crystals and matrix, and crystal sizes, and the translucency of zirconia is affected by grain size and crystalline phase content.[24,25] In addition, the translucency of ceramic materials is affected by the pores, grain boundaries, and scattering from rough surfaces.[24,25] Improving the strength of ceramic materials tends to decrease translucency. TP values of human dentin and enamel with a thickness of 1.0 mm were known as 16.4 and 18.1, respectively.[26] TP values for tested ceramic materials were comparable to those of natural teeth.

Based on the findings, the translucency of CAD-CAM ceramic restorative materials negatively affects the accuracy of IOS scan without a scanning aid; however, the scan accuracy and time efficiency of IOS scanning for anatomic contour ceramic restorations can be improved by applying scanning aid, and prostheses with high quality without unnecessary labor can be produced.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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