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Accuracy of inter-arch measurements performed on digital models generated using two types of intraoral scanners: Ex vivo study

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ABSTRACT

Accuracy of inter-arch measurements performed on digital models generated using two types of intraoral scanners: Ex vivo study

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Objective: The purpose of this study was to evaluate the accuracy of the inter-arch relationship of digital models generated using two types of intraoral scanners.

Methods: In total, 34 plaster model samples were used. Two corresponding digital models were created using two types of intraoral scanners. A total of 15 variables were measured. The plaster model was directly measured using a digital caliper, while the digital models were measured using a software. The accuracy of the measurements was evaluated using repeated measures analysis of variance and the Friedman test.

Results: Among the 15 measurements, 6 measurements[Overjet, Overbite, DZ_11-41 (Distance between the gingival zenith of maxillary right central incisor and mandibular right central incisor), DZ_16-46 (Distance between the gingival zenith of maxillary right first molar and mandibular right first molar), DZ_13-33 (Distance between the gingival zenith of maxillary right canine and mandibular left canine), and DZ_23-43 (Distance between the gingival zenith of maxillary left canine and mandibular right canine)]showed statistically significant differences, with DZ_23-43 showing the largest difference of 0.18 mm. The other measurements showed no statistically significant differences.

Conclusions: Regardless of the type of scanner used for preparation, digital models can be used as clinically acceptable alternatives to conventional plaster models.

Key words: Digital models, 3D intraoral scanner, Inter-arch measurements

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Ⅰ. INTRODUCTION

Advances in three-dimensional technology and digital devices have led to considerable changes in clinical orthodontics as well as orthodontic diagnostics.[1,2] Plaster models are considered the gold standard for diagnosis and treatment planning in orthodontics.[2,3] They can be used for precise simulation of the patient's oral cavity and are used in several types of analyses for orthodontic treatment. However, plaster and impression materials such as alginate are required for their preparation; moreover, considerable space is needed for their storage. There are also concerns about breakage, discoloration, and abrasion, as well as discomfort caused to the patient while recording the impression.[4-6]

Digital models obtained using an intraoral scanner do not present any issues in terms of storage space and preparation time, and they can be conveniently used for sharing data with other researchers or dentists. With the use of digital models, it is also possible to reduce costs associated with materials such as plaster and alginate or other impression materials; furthermore, processes such as diagnostic setup are easy. In patients who display a gag reflex, digital scanning can reduce the discomfort associated with the use of impression materials.[7-13]

A number of studies have assessed and compared the accuracy and reproducibility of measurements between plaster models and digital models; the difference, if present, was either not statistically significant or was at a clinically acceptable level.[1,2,4,6-8,14-18] However, most studies only examined intra-arch measurements, and research on inter-arch measurements, which are essential for diagnosis and treatment planning, is scarce.[14,15] Therefore, for digital models to replace plaster models as tools for diagnosis and treatment planning, it is necessary to verify the absence of statistically or clinically significant differences between the two types of models especially inter-arch measurements.[11,14-16]

In plaster models, the occlusal relationship between the maxilla and mandible can be readily identified by visual inspection and tactile sensation; therefore, there are no particular difficulties in analyzing the inter-arch relationship.[2,4] In contrast, in digital images, the maxilla and mandible are scanned first, followed by the occlusal relationship. Then, the occlusion between the maxillary and mandibular arches is established using a digital program. Here, touch perception cannot be used, and occlusion can only be visually inspected depending on the settings of the program.[3,14] Therefore, the measurement results may differ depending on the hardware and software being used. Consequently, measurements obtained from digital models produced by intraoral scanners need to be tested for accuracy before the use of these models as alternatives to plaster models.[3,16,19]

To the best of our knowledge, only few studies have compared the accuracy of inter-arch relationships measured on digital models prepared using two different types of intraoral scanners with those measured on conventional plaster models. Therefore, in the present study, we investigated whether digital models created using intraoral scanners showed any differences from plaster models in terms of various inter-arch measurements. Trios (3Shape, Copenhagen, Denmark) and PlanScan (Planmeca, Helsinki, Finland) intraoral scanners are widely used in dentistry now. Since both scanners have not the same accuracy, it would be meaningful to compare their relative scanning accuracy. In this purpose, two types of intraoral scanners were used in the study.

Ⅱ. MATERIALS AND METHODS

This study was approved by the institutional review board (GCIRB 2018-352). We examined plaster models that were fabricated for diagnosis and reviewed the clinical data of patients who had visited the Department of Orthodontics at our institution for orthodontic treatment or consultation between March 2012 and February 2017. We selected models that were properly stored without any breakage and limited patients to those having a permanent dentition. We excluded patients who had lost >2 teeth, patients with a level of abrasion that could cause measurement errors, patients with anterior crossbite or open bite, and patients with a syndrome such as cleft lip and palate. We did not include any data that contained personal information, such as the patient's age or sex, and plaster models were assigned only numbers for identification.

Thirty-four plaster models were scanned using two different intraoral scanners. In this manner,

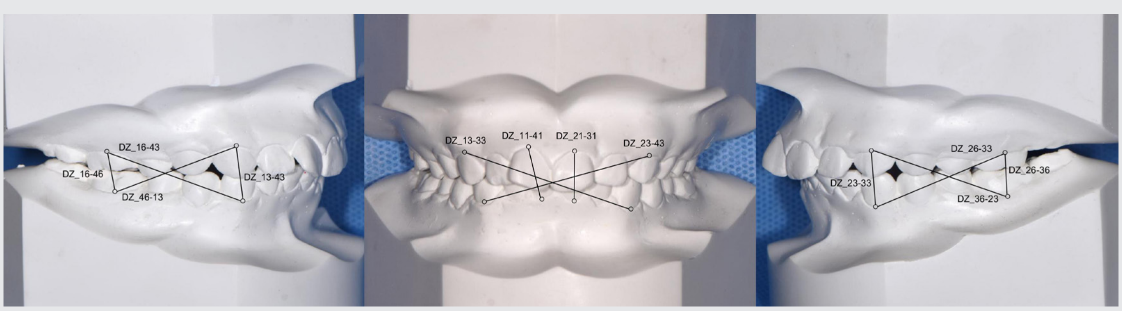

Figure 1. Measurements performed in this study. DZ_11–41, Distance between the gingival zenith of #11 and #41; DZ_13–43, Distance between the gingival zenith of #13 and #43; DZ_16–46, Distance between the gingival zenith of #16 and #46; DZ_21–31, Distance between the gingival zenith of #21 and #31; DZ_23–33, Distance between the gingival zenith of #23 and #33; DZ_26–36, Distance between the gingival zenith of #26 and #36; DZ_13–33, Distance between the gingival zenith of #13 and #33; DZ_23–43, Distance between the gingival zenith of #23 and #43; DZ_16–43, Distance between the gingival zenith of #16 and #43; DZ_26–33, Distance between the gingival zenith of #26 and #33; DZ_36–23, Distance between the gingival zenith of #36 and #23; DZ_46–13, Distance between the gingival zenith of #46 and #13.

Table 1. Definitions of inter–arch measurements

Measurement (mm)	Definition	Note	Method error[a]	
			manual	digital
Midline	Horizontal distance between the midline of maxillary dental arch and the midline of mandibular dental arch	Absolute value	0.13	0.07
Overjet	Horizontal overlap of the maxillary central incisors over the mandibular central incisors		0.11	0.04
Overbite	Vertical overlap of the maxillary central incisors over the mandibular central incisors		0.13	0.04
DZ_11–41	Distance between #11 gingival zenith and #41 gingival zenith		0.13	0.10
DZ_13–43	Distance between #13 gingival zenith and #43 gingival zenith		0.14	0.10
DZ_16–46	Distance between #16 gingival zenith and #46 gingival zenith		0.19	0.13
DZ_21–31	Distance between #21 gingival zenith and #31 gingival zenith		0.13	0.11
DZ_23–33	Distance between #23 gingival zenith and #33 gingival zenith		0.09	0.14
DZ_26–36	Distance between #26 gingival zenith and #36 gingival zenith		0.14	0.12
DZ_13–33	Distance between #13 gingival zenith and #33 gingival zenith		0.13	0.09
DZ_23–43	Distance between #23 gingival zenith and #43 gingival zenith		0.12	0.11
DZ_16–43	Distance between #16 gingival zenith and #43 gingival zenith		0.10	0.10
DZ_26–33	Distance between #26 gingival zenith and #33 gingival zenith		0.13	0.13
DZ_36–23	Distance between #36 gingival zenith and #23 gingival zenith		0.14	0.09
DZ_46–13	Distance between #46 gingival zenith and #13 gingival zenith		0.16	0.12

[a] Method errors are calculated by Dahlberg formula.

34 Trios digital models (hereafter, Trios) and 34 PlanScan digital models (hereafter, PlanScan) were generated. All scans were performed by the same researcher according to the recommendations of each manufacturer. In the event of an error during scanning, previous data were deleted and the entire scanning procedure was repeated.

A total of 15 variables were measured (Table 1, Figure 1). The plaster models were measured to the 0.01 mm using digital caliper (Mitutoyo, Tokyo, Japan), while the digital models were measured to the 0.01 mm using OrthoAnalyzer software (3Shape). In order to improve the accuracy of inter-arch measurements on the plaster models, the maxilla and mandible were placed in occlusion and fixed using sticky wax to prevent movement.

Among the different measured variables, Overjet and Overbite can show additional errors in the lengths measured by digital calipers or software that are beyond the actual difference in length, especially, if the reference plane is not the same. Therefore, it is necessary to use the same reference plane for all measurements on plaster and digital models. However, in previous studies using inter-arch measurements, there was no or insufficient explanation about the use of the same reference plane for different models.[4,14,20] Therefore, in the present study, we attempted to use a single reference plane using the method below in order to reduce the bias.

In the OrthoAnalyzer software used to measure the digital models, the occlusal plane is defined using three specific points on the maxillary model when setting the occlusion. In our study, these three points were in the middle of the central incisors and the central pit of the bilateral first molars. When scanning the digital models and obtaining measurements from the plaster models, we attempted to use the same occlusal plane. First, we checked the same three points on the plaster model and subsequently trimmed the base of the maxillary cast such that it was parallel to the plane formed by these three points. Thereafter, we placed the maxillary and mandibular casts in occlusion and fixed them with sticky wax to prevent movement. Finally, we turned over the fixed model such that the base of the maxillary cast rested on the table and measured Overjet, ensuring that the occlusal plane was parallel to the surface of the table. To measure Overbite, we identified the point where the incisal edge of the maxillary central incisors met the labial surface of the mandibular central incisors in a direction parallel to the occlusal plane.

All measurements were performed by a single researcher. For reproducibility assessments, 30 of the 102 models were randomly selected after 2 weeks and measured by the same researcher following the same methods. The intraclass correlation coefficient was thus calculated.

III. STATISTICAL ANALYSIS

The required sample size for repeated measures analysis of variance (ANOVA) with a significance level of 0.05 and a power of 0.80 was calculated to be 28 using G*power (version 3.1.9.2). Accounting for unpredictable circumstances such as breakage or loss of plaster models during measurements, we selected 34 plaster models.

Method errors in all variables were calculated using the Dahlberg formula (Table 1).[21] According to the results of the Shapiro-Wilk test for normality, Midline and Overjet did not show normal distribution, whereas the other 13 variables satisfied the conditions of normality. Repeated measures ANOVA (parametric) and the Friedman test (nonparametric) were applied for the 13 normally distributed variables and two variables with non-normal distribution, respectively. Repeated measures ANOVA was performed with Bonferroni correction for post hoc analysis of the main effect. For the Friedman test, post hoc analysis involved the Bonferroni-adjusted Wilcoxon rank sum test for multiple comparisons. For multiple comparisons in post hoc analysis, a significance level of 0.017 (0.05/3) was used. For all other statistical analyses, a significance level of 0.05 was used.

Bland-Altman plots[22] were used for visual inspection of differences among measurements obtained using the three different methods. Plots were drawn for each pair of methods with three variables showing the strongest statistically significant differences.

All statistical analyses were performed using SPSS 12.0 for Windows (IBM Corp., Armonk, NY, USA).

Ⅳ. RESULTS

The intraclass correlation coefficient was over 0.95 for all variables, indicating excellent reliability.

Statistically significant differences were observed for Overjet, Overbite, DZ_11-41, DZ_16-46, DZ_13-33, and DZ_23-43. Overjet showed higher ranks for Plaster and Trios than for PlanScan, while the difference in ranks between Plaster and Trios was not statistically significant. The mean Overbite was 2.16 mm for Plaster and 2.09 mm for Trios, the mean DZ_11-41 was 16.29 mm for Plaster and 16.41 mm for PlanScan, and the mean DZ_16-46 was 12.18 mm for Plaster and 12.31 mm for Trios; the difference was statistically significant for all variables. The mean DZ_13-33 was 38.55 mm for Plaster, and this value was significantly different from the values for both PlanScan (38.41 mm) and Trios (38.41 mm). The mean DZ_23-43 was 37.38 mm for Trios, and this value was significantly different from the values for both PlanScan (37.55 mm) and Plaster (37.56 mm) (Table 2).

We constructed Bland-Altman plots for Overjet, DZ_13-33, and DZ_23-43 which showed the strongest significant differences. The largest mean difference was observed between DZ_23-43 measured by Plaster and that measured by Trios (0.18 mm). In the PlanScan-Trios plot for DZ_13-33 and the Plaster-PlanScan plot for DZ_23-43, three values each were outside the upper/lower 95% limits of agreement. The other plots showed fewer than three values beyond the limits of agreement (Figure 2, 3, 4).

Table 2. Comparison of inter–arch measurements among Plaster, PlanScan, Trios groups

	Measurements	Plaster			PlanScan			Trios			p–value	
		mean	SD	Mean Rank	mean	SD	Mean Rank	mean	SD	Mean Rank	by RM ANOVA[a]	by Friedman test[b]
Inter–arch	Midline	1.06	0.67	1.96	1.07	0.67	2.18	1.05	0.64	1.87		0.409
	Overjet	3.16	1.30	2.06^{C}	3.05	1.32	1.41^{D}	3.21	1.35	2.53^{C}		<0.001*
	Overbite	2.16^{A}	1.05		2.11^{AB}	1.03		2.09^{B}	1.06		0.045*	
	DZ_11–41	16.29^{A}	1.88		16.41^{B}	1.88		16.36^{AB}	1.86		0.005*	
	DZ_13–43	17.31	2.03		17.28	2.08		17.32	2.02		0.500	
	DZ_16–46	12.18^{A}	1.52		12.23^{AB}	1.54		12.31^{B}	1.55		0.004*	
	DZ_21–31	16.29	1.77		16.36	1.78		16.31	1.77		0.189	
	DZ_23–33	17.57	2.32		17.57	2.34		17.58	2.27		0.954	
	DZ_26–36	12.25	1.65		12.31	1.71		12.26	1.62		0.257	
	DZ_13–33	38.55^{A}	2.36		38.41^{B}	2.38		38.41^{B}	2.36		<0.001*	
	DZ_23–43	37.56^{A}	2.06		37.55^{A}	2.07		37.38^{B}	2.03		<0.001*	
	DZ_16–43	30.89	2.01		30.89	2.04		30.88	2.06		0.987	
	DZ_26–33	30.51	1.98		30.60	2.05		30.58	2.00		0.175	
	DZ_36–23	25.68	2.52		25.76	2.45		25.69	2.49		0.137	
	DZ_46–13	24.90	2.36		24.83	2.32		24.84	2.25		0.247	

[a] Repeated measures analysis of variance(RM ANOVA) and [b] Friedman test were performed among Plaster, PlanScan, and Trios groups.
[A, B] Main effect comparison with Bonferroni adjustment for each pairwise comparison.
[C, D] Wilcoxon ranksum test with Bonferroni adjustment for each pairwise comparison.
The groups sharing the same capital superscript (A, B, C, D) in same raw show they are not significantly different.
* Statistically significant at 0.05 level of confidence.

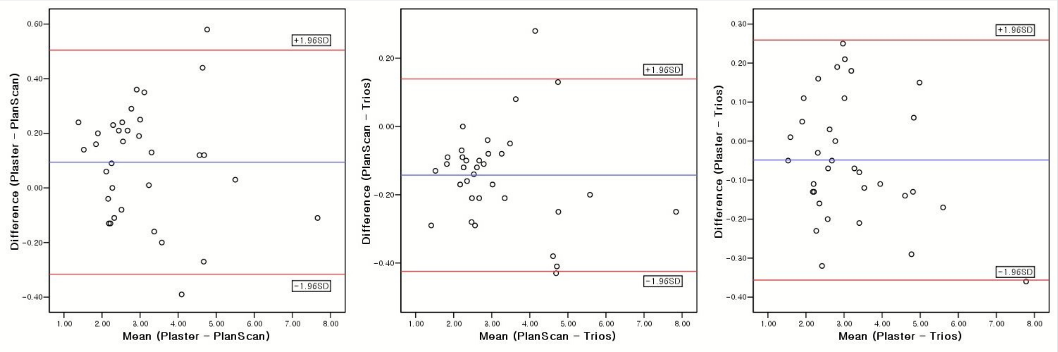

Figure 2. Bland-Altman plots for the comparison of Overjet among a plaster model and two digital models prepared using different intraoral scanners.

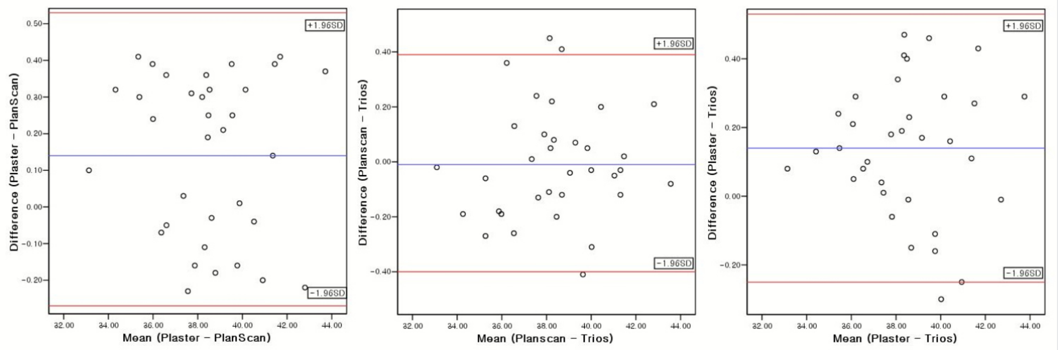

Figure 3. Bland-Altman plots for the comparison of DZ_13-33 among a plaster model and two digital models prepared using different intraoral scanners.

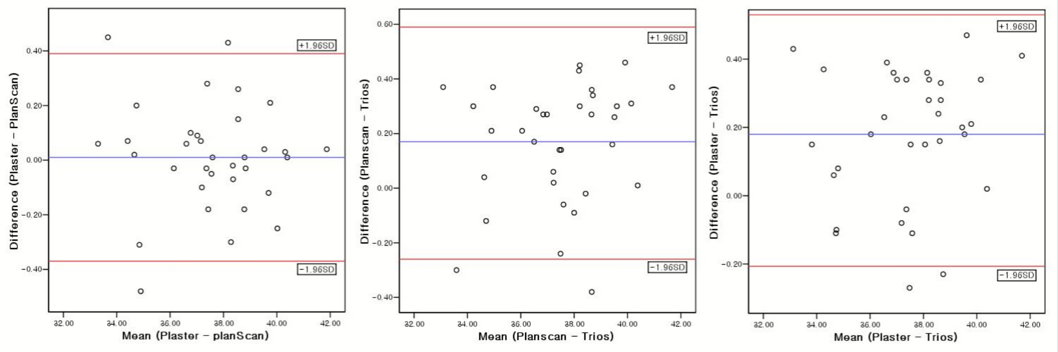

Figure 4. Bland-Altman plots for the comparison of DZ_23-43 among a plaster model and two digital models prepared using different intraoral scanners.

V. DISCUSSION

According to Fleming et al.[7] and Rossini et al.,[23] a number of previous studies have compared linear measurements in a single arch between plaster models and digital models generated using various methods and found similar levels of accuracy and reproducibility. Also, in the Anh et al.[12] and Yoon et al.[18]'s studies, there was no significant difference about the accuracy of digital models generated from the various degree of the tooth crowding cases.

In orthodontic diagnosis and analysis, it is essential to examine inter-arch measurements.[14,15] Although some studies have reported inter-arch measurements, they only measured the midline, overjet, and overbite, which are all within the anterior tooth region.[7,23] Reuschl et al.[20] compared inter-arch measurements between plaster models and a digital model using the same software used in our study; however, their measurements were also limited to the anterior region. Sweeney et al.[4], Kiviahde et al.[15] and Porter et al.[24] measured the canines and posterior teeth, although they obtained only vertical measurements. Therefore, we overcame the limitation of the previous study by including more transverse and anteroposterior measurements.

According to Darroudi et al.,[14] there is a high probability of error when the operator is involved in setting the occlusion of digital models. Therefore, software is ultimately required to automate this process. In our study, we minimized researcher intervention outside the scanning procedure and during the generation of digital models. Unlike the design of Sweeney et al.[4] and Porter et al.,[24] the measurements were made using actual landmarks without the marking of any indentations on the surface, and the results showed that these measurements were sufficiently accurate.

Among the measurements used in our study, only Overjet, Overbite, DZ_11-41, DZ_16-46, DZ_13-33, and DZ_23-43 showed statistically significant differences, with the largest difference observed in DZ_23-43 measured on Plaster and that measured on Trios (0.18 mm). The differences in the other variables were small: 0.07 mm, 0.12 mm, 0.13 mm, and 0.14 mm for Overbite, DZ_11-41, DZ_16-46, and DZ_13-33 respectively. Apart from Overjet and DZ_23-43, we observed no statistically significant differences in any other variables between the two digital models. Plaster and Trios each showed higher values for Overjet than did PlanScan, and on average, Overjet was 0.16 mm larger on Trios than on PlanScan. This difference is considered clinically acceptable.[20,23]

In the Bland-Altman plots, apart from 0-3 data points, all other data points were within the upper/lower 95% limits of agreement. However, in the comparison of Overjet between Plaster and PlanScan, one data point showed a large difference of 0.58 mm, exceeding the upper limit of agreement. This is also slightly higher than the clinically acceptable limit of 0.5 mm suggested by Reuschl et al.,[20] and it was probably associated with an error in the process of measuring Overjet. The PlanScan measurement was smaller than the Plaster measurement; however, because the other 33 specimens did not show this trend, it was determined to be a singular measurement error. Although it could be an error in the intraoral scanner program, the setup of our study did not allow this possibility to be investigated. However, it should be emphasized that this possibility is minimal because all other measurements from this specimen did not show the same trend. The mean difference in Overjet measured by the two scanners was the largest, although it was only 0.16 mm. For DZ_13-33 and DZ_23-43, there were no differences that exceeded the limits of clinical acceptability.[20] Unlike Overjet, DZ_13-33 showed the smallest mean difference between the two intraoral scanners (0.01 mm). The plots for Overjet, DZ_13-33, and DZ_23-43 did not show any particular trends such as linearity or increasing variance. In addition, given that the mean differences were in the range of 0.01-0.18 mm, we could not detect any trend for a single method in terms of overestimation or underestimation of measurements relative to those derived by the other methods.[22,25] On the basis of these data, we judged that the digital models obtained using both types of intraoral scanners have sufficient accuracy and can replace plaster models for orthodontic diagnosis and treatment planning.

This study using the intraoral scanner has a meaning that is closer to the clinical reality than that of Kiviahde et al.[15] using the model scanner. However, there is a limit to using an image scanned by a model rather than a direct scanning of the oral cavity. According to Anh et al.[12] and Mack et al.,[17] the error in digital models is larger for the posterior teeth than for the anterior teeth because of scanning techniques and reduced accessibility. So it will be necessary to use a study design wherein digital models are generated by direct scanning of the oral cavity, not by scanning plaster models. This would eventually allow for analysis of the inter-arch relationship for orthodontic diagnosis and treatment using only digital models scanned from the oral cavity. Additionally, inclusion of an increased number of examiners to test the inter-observer accuracy will help in validating the results of the study.

Vertical measurements are also important, but the accuracy of the occlusal contacts should be evaluated to better assess the occlusal relationship. According to Sweeney et al.[4] and Darroudi et al.,[14] the accuracy of the occlusal relationship is reduced due to the inaccuracy of digital bites. And there is a problem that the occlusal relationship which cannot be physically in plaster model can appear without limitation in the digital bite. In subsequent studies, therefore, it is necessary to investigate whether the occlusal contact points in the oral cavity match the occlusion contact points in the digital model obtained by intraoral scanning. Recently, there was a research to evaluate the tooth movement using a serial intraoral scanning from the patients undergoing orthodontic treatment.[26] It is expected that there will be various clinical applications of intraoral scanners in the near future.

VI. CONCLUSION

Within the limitations of this study, our conclusions are as follows:

1. Among the 15 measurements, six variables showed statistically significant differences, the largest mean difference was 0.18 mm. This difference is at a clinically acceptable level.
2. The digital models obtained using the two types of intraoral scanners showed sufficient accuracy and can be used instead of plaster models in clinical orthodontics.

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