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CLINICAL RESEARCH

Influence of occlusal collision corrections completed by two intraoral scanners or a dental design program on the accuracy of the maxillomandibular relationship

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ABSTRACT

Statement of problem. Occlusal collisions of articulated intraoral digital scans can be corrected by intraoral scanners (IOSs) or dental design software programs. However, the influence of these corrections on the accuracy of maxillomandibular relationship is unclear.

Purpose. The purpose of this clinical investigation was to measure the effect of occlusal collision corrections completed by the IOSs or dental design software programs on the trueness and precision of maxillomandibular relationship.

Material and methods. Casts of a participant mounted on an articulator were digitized (T710). The experimental scans were obtained by using 2 IOSs: TRIOS4 and i700. The intraoral digital scans of the maxillary and mandibular arches were obtained and duplicated 15 times. For each duplicated pair of scans, a bilateral virtual occlusal record was acquired. Articulated specimens were duplicated and assigned into 2 groups: IOS-not corrected and IOS corrected (n=15). In the IOS-not corrected groups, the IOS software program postprocessed the scans maintaining the occlusal collisions, while in the IOS-corrected groups, the IOS software program eliminated the occlusal collisions. All articulated specimens were imported into a computer-aided design (CAD) program (DentalCAD). Three subgroups were developed based on the CAD correction: CAD-no change, trimming, or opening the vertical dimension. Thirty-six interlandmark distances were measured on the reference and each experimental scan to compute discrepancies by using a software program (Geomagic Wrap). Root mean square (RMS) was selected to compute the cast modifications performed in the trimming subgroups. Trueness was examined using 2-way ANOVA and pairwise comparison Tukey tests (α=.05). Precision was evaluated with the Levene test (α=.05).

Results. The IOS (*P*<.001), the program (*P*<.001), and their interaction (*P*<.001) impacted the trueness of the maxillomandibular relationship. The i700 obtained higher trueness than the TRIOS4 (*P*<.001). The IOS-not corrected-CAD-no-changes and IOS-not-corrected-trimming subgroups obtained the lowest trueness (*P*<.001), while the IOS-corrected-CAD-no-changes, IOS-corrected-trimming, and IOS-corrected-opening subgroups showed the highest trueness (*P*<.001). No significant differences in precision were found (*P*<.001). Furthermore, significant RMS differences were found (*P*<.001), with a significant interaction between Group×Subgroup (*P*<.001). The IOS-not corrected-trimmed subgroups obtained a significantly higher RMS error discrepancy than IOS-corrected-trimmed subgroups (*P*<.001). The Levene test showed a significant discrepancy in the RMS precision among IOSs across subgroups (*P*<.001).

Conclusions. The trueness of the maxillomandibular relationship was influenced by the scanner and program used to correct occlusal collisions. Better trueness was obtained when the occlusal collisions were adjusted by the IOS program compared with the CAD program. Precision was not significantly influenced by the occlusal collision correction method. CAD corrections did not improve the results of the IOS software. Additionally, the trimming option caused volumetric changes on the occlusal surfaces of intraoral scans. (J Prosthet Dent 2023;■:■-■)

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Clinical Implications

To maximize the trueness of the maxillomandibular relationship at the MIP recorded by the tested IOSs, the occlusal collisions of the articulated intraoral digital scans should be adjusted during the automatic postprocessing procedures completed by the IOSs' software program.

An accurate maxillomandibular relationship between the maxillary and mandibular casts is fundamental to prosthodontic practice.[1,2] In the integration of intraoral scanners (IOSs) for different dental interventions,[3] the accuracy of the digitizing methods recording the maxillomandibular relationship is similarly essential. The maxillomandibular relationship accuracy recorded by using IOSs has been analyzed in various in vitro and clinical studies.[4-16] These studies have compared the accuracy of the maxillomandibular relationship at maximum intercuspation position (MIP) acquired by using IOSs and conventional methods.[4-15] The majority of these studies reported that IOSs can achieve a similar maxillomandibular relationship compared with conventional techniques.[4-15]

Intraoral digital scans are recorded in an unload condition, with the mouth open, while acquiring the maxillary and the mandibular intraoral scans.[17-19] This condition changes when capturing the virtual occlusal records at MIP. Occlusal collisions or mesh interpenetrations have been identified when virtual articulated casts penetrate each other.[17-19] Occlusal collisions are caused by the tooth location discrepancy resulting from the periodontal ligament plasticity between the recording of the intraoral digital scans and the virtual occlusal records, as well as from the intraoral scanning distortion and alignment procedures.[17-19] The software programs of the IOSs can automatically eliminate the occlusal collisions present in virtual articulated casts. Similarly, dental computer-aided design (CAD) programs can automatically detect and eliminate occlusal collisions among the articulated intraoral digital scans imported. However, the effect of the occlusal collision corrections performed by using IOSs or CAD programs on the accuracy of the maxillomandibular relationship at MIP recorded is unknown.

The goal of this clinical investigation was to assess the impact of occlusal collision corrections performed by the software program of 2 IOSs (TRIOS4; 3Shape A/S, i700; Medit) and a dental CAD program (DentalCAD, Rijeka; exocad GmbH) on the trueness and precision of the maxillomandibular relationship acquired at MIP. The null hypotheses were that no difference would be found in the trueness and precision of the maxillomandibular relationship at MIP captured by the different collision correction methods assessed, independently of the IOS selected to record the data and that no difference would be found in the trueness and precision of the maxillomandibular relationship at MIP recorded by the IOSs tested.

MATERIAL AND METHODS

The research methodology of this manuscript was reviewed by the Institutional Review Board (IRB) of the School of Dentistry at the Complutense University of Madrid (CE_20220217-01_SAL) (Fig. 1). A completely dentate patient without indirect restorations or temporomandibular popping, discomfort, or sounds volunteered to participate in the study.

A conventional polyvinyl siloxane impression (Virtual heavy and light viscosity regular set; Ivoclar Vivadent AG) of the maxillary and mandibular arch was acquired. The impressions were poured in Type IV stone (GC Fujirock EP; GC) by following the manufacturer's instructions (100 g dental stone, mixed with 22 mL water under vacuum for 30 seconds). A facebow record (Kois Dento-Facial Analyzer; Panadent Corp) was captured to mount the maxillary cast on a semiadjustable dental articulator (Panadent Articulator, PCH; Panadent Corp). The mandibular cast was hand mounted on the same articulator (Fig. 2).[20] The stone casts were scanned by using a desktop scanner (T710; Medit) by following the protocol of the manufacturer, and the reference standard tessellation language (STL) files were obtained.

Two IOS were selected to record the experimental digital scans: TRIOS4 (TRIOS4, wireless, v. 22.2.3; 3Shape A/S) and i700 (i700, wireless; Medit). Two groups were established depending on the correction of the occlusal collisions performed by using the IOS software program: not corrected (IOS-not corrected group) and IOS corrected (IOS-corrected group). Moreover, 3 subgroups were established based on the correction procedures performed in a dental CAD program (DentalCAD, Rijeka; exocad GmbH): no changes (CAD-no changes subgroup), cast trimming (trimming subgroup), or opening the vertical dimension (opening subgroup) (Fig. 1).

All the intraoral digital scans were captured in a room at 1000-lux illumination settings (LX1330B Light Meter; Dr. Meter Digital Illuminance).[21-23] Each IOS was calibrated before obtaining the data and after every 10 digitizing procedures.[24] IOS calibration procedures were performed by following the instructions of each IOS manufacturer. Data collection procedures for obtaining maxillary and mandibular digital scans and virtual occlusal records were recorded using the scanning pattern of each IOS manufacturer. The intraoral digital scans were recorded without mesh holes and without

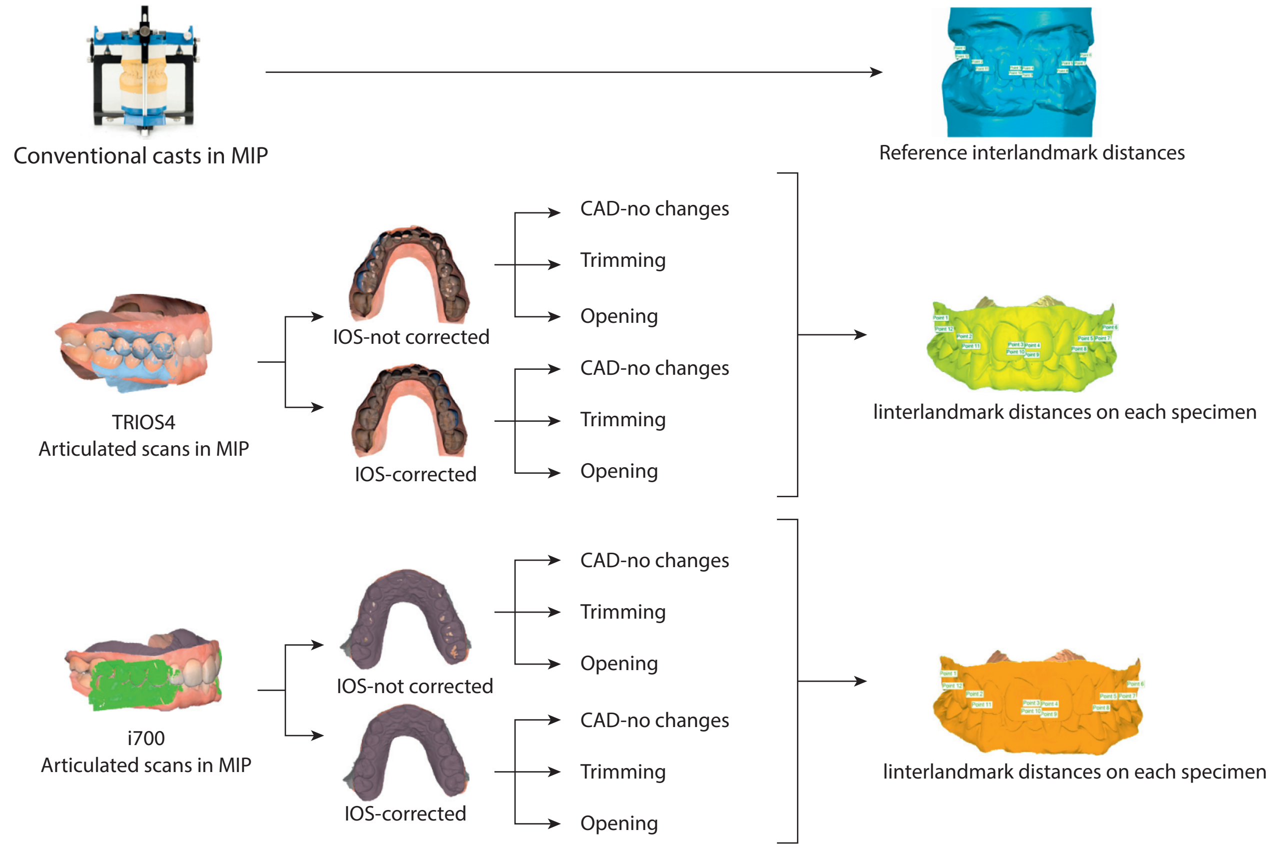


Figure 1. Scheme of research methodology. CAD, computer-aided design; IOS, intraoral scanner; MIP, maximum intercuspation position.

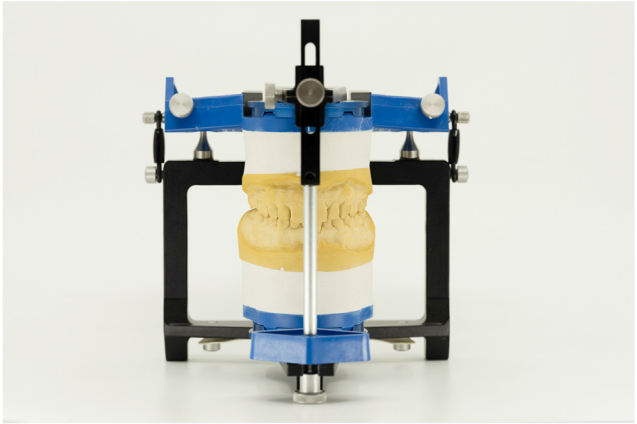


Figure 2. Maxillary and mandibular conventional diagnostic stone cast mounted on semiadjustable articulator.

rescanning procedures,[25,26] and the maxillary scans did not include the palate. The scanning distance used to acquire the data using both IOSs ranged from 0 to 2 mm.[27] All the data were acquired by a prosthodontist (M.R.-L.) with 10 years of experience with IOSs.

To acquire the data using the TRIOS4, a maxillary and mandibular intraoral scan were recorded. The reliability function was activated when acquiring the data (blue to brown color visualization mode). Subsequently, the scans were duplicated 15 times using the IOS program. Then, the participant was positioned at 45 degrees in a dental chair.[28,29] Subsequently, for each pair of duplicated digital scans, a bilateral occlusal record including 4 teeth (from the first molar to the canine) was obtained at MIP position (Fig. 3A).[14] Lastly, the 15 articulated digital casts (not postprocessed) were duplicated using the IOS program. Two identical groups of 15 articulated intraoral digital scans at MIP were obtained (not postprocessed) and were assigned to each group: TRIOS4-IOS-not corrected and TRIOS4-IOS corrected groups (n=15).

In the TRIOS4-IOS not corrected group, the function "adjust for occlusions" was deactivated (Fig. 3B); therefore, the occlusal collisions were not eliminated by the IOS program during the postprocessing procedures. After the automatic postprocessing procedures, the articulated digital scans were acquired in an STL file format. In the TRIOS4-IOS corrected group, the function "adjust for occlusions" was activated (Fig. 3C); therefore, the occlusal collisions were automatically eliminated by the IOS program during the postprocessing procedures. After the postprocessing procedures, the STL file of the articulated digital scans was obtained.

To record the data using the i700 group, the focal length selected in the IOS software program was 23 mm.

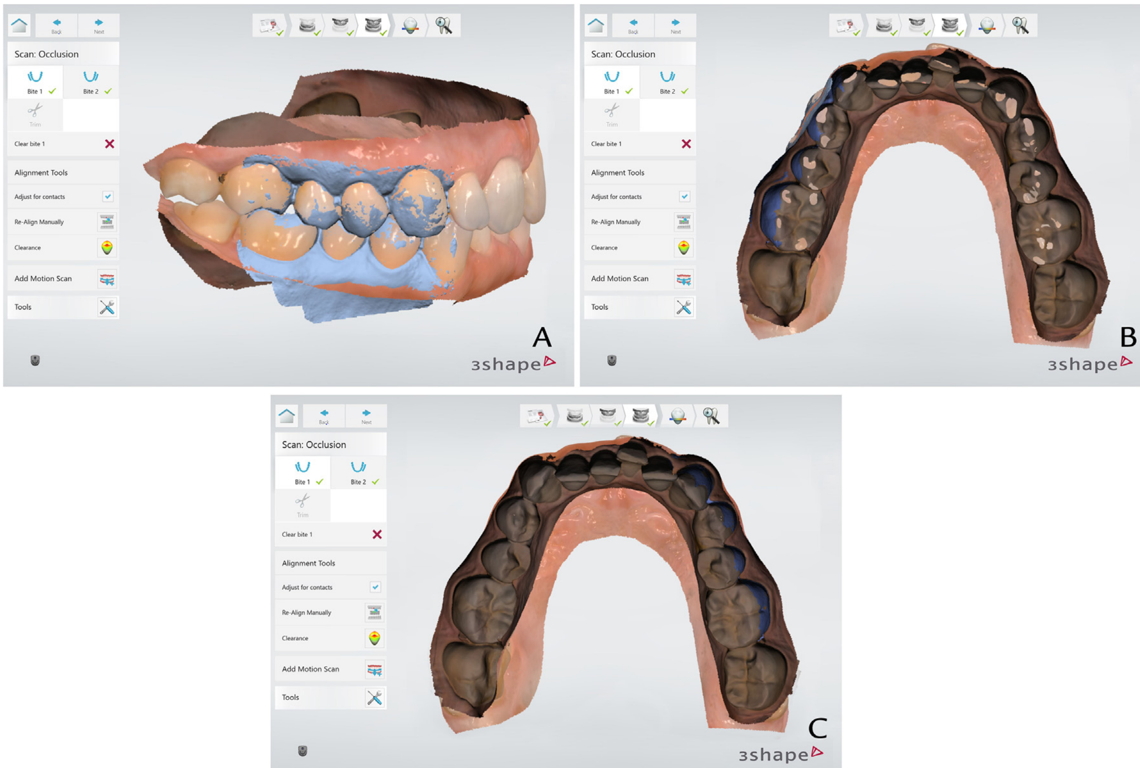


Figure 3. A, Representative virtual intraoral digital scans articulated at MIP using TRIOS4 IOS. B, TRIOS4-IOS not corrected group. C, TRIOS4-IOS corrected group. IOS, intraoral scanner; MIP, maximum intercuspation position.

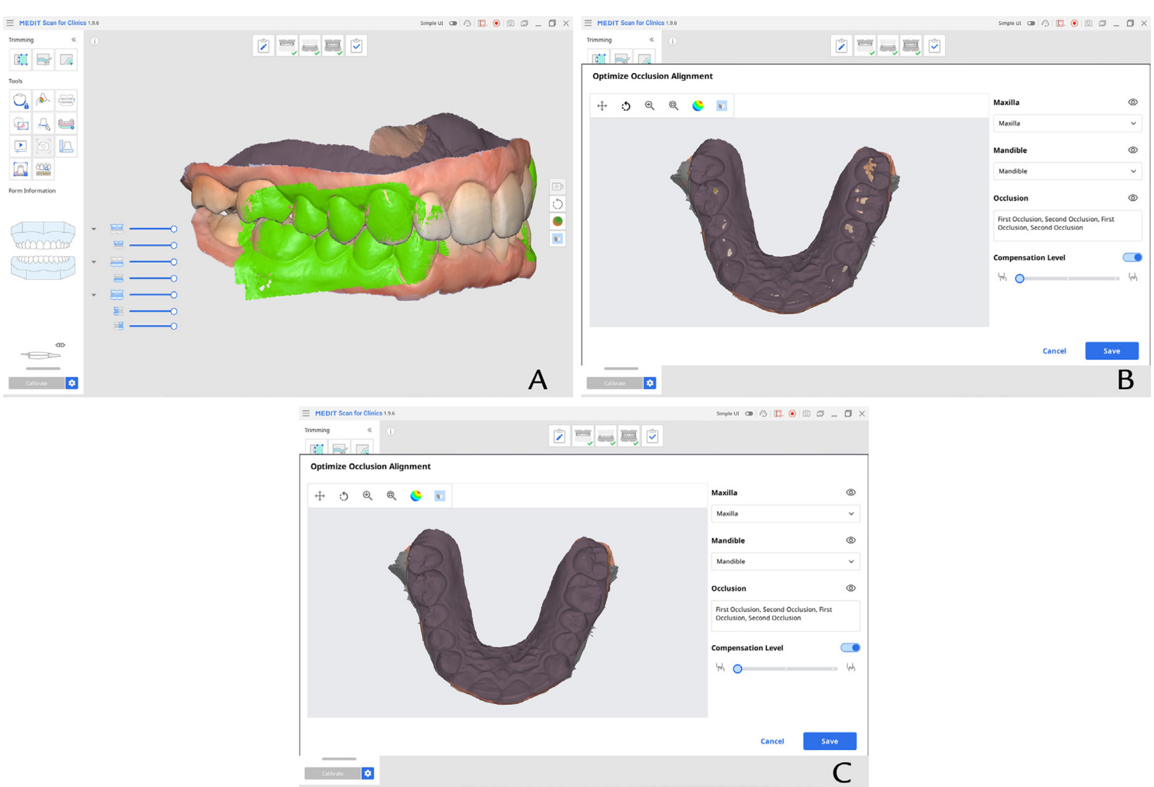


Figure 4. A, Representative virtual intraoral digital scans articulated at MIP using i700 IOS. B, i700-IOS not corrected group. C, i700-IOS corrected group. IOS, intraoral scanner; MIP, maximum intercuspation position.

Figure 5. A, Representative articulated specimen mounted on virtual semiadjustable articulator (Panadent Articulator. B, CAD program detecting occlusal collisions among articulated specimens in which two options available: making no changes or trimming the casts.

The smart stitching, smart color, and smart scan filtering functions were disabled. The reliability function was activated when acquiring the data (red to green visualization mode). Additionally, the same acquisition methods were performed as completed in the TRIOS4 group (Fig. 4A). Therefore, 2 identical groups of 15 articulated maxillary and mandibular intraoral digital scans at MIP were acquired (not postprocessed) and were assigned to each group: i700-IOS not corrected and i700-IOS corrected groups (n=15).

In the i700-IOS not corrected group, the "occlusal alignment optimization" function of the IOS settings was disabled (Fig. 4B); therefore, the occlusal collisions were maintained by the IOS software program during the postprocessing procedures. Afterward, the articulated scans were captured in an STL file format. In the i700-IOS corrected group, the "occlusal alignment optimization" function of the IOS settings was activated to the maximum level (Fig. 4C); therefore, the occlusal collisions were automatically eliminated by the IOS software program. Then, the articulated scans were recorded in STL file format.

All the STL files obtained in the TRIOS4-IOS not corrected, TRIOS4-IOS corrected, i700-IOS not

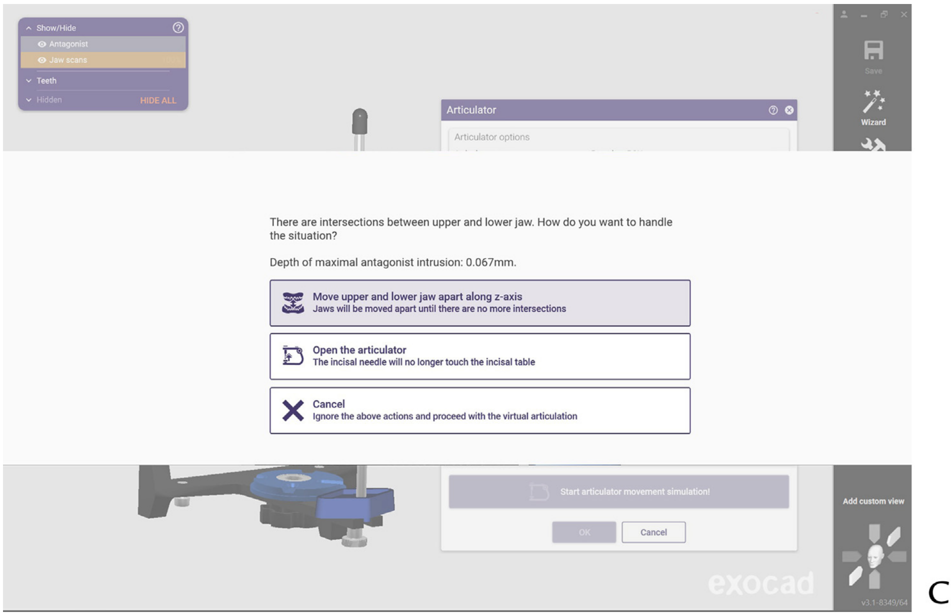


Figure 5. (*Continued*) C, If no changes selected, CAD program provides 3 options: making no changes, opening vertical dimension among articulated casts, or opening incisal pin of articulator. CAD, computer-aided design.

corrected, and i700-IOS corrected groups were imported into the selected dental program (DentalCAD, Rijeka; Exocad GmbH). The purpose was to simulate the adjustments that can be completed in the articulated intraoral digital scans by using the selected dental design program. Each articulated specimen was mounted onto the virtual articulator (Panadent Articulator; Panadent Corp) by following the technique described by Kois et al.[30] This dental design program automatically detected occlusal collisions among articulated intraoral digital scans. The program offered 2 possibilities for removing them: trimming the occlusal surfaces of the casts or opening the virtual dimension between the maxillary and mandibular intraoral digital scans until the occlusal collisions were eliminated (Fig. 5). Therefore, all the specimens were modified by following 3 possible procedures: no changes (CAD-no changes subgroup), trimming the virtual casts (trimming subgroup), or opening the vertical dimension (opening subgroup).

In the TRIOS4-IOS not corrected trimming, TRIOS4-IOS corrected trimming, i700-IOS not corrected trimming, and i700-IOS corrected trimming subgroups, the dental design program automatically trimmed the maxillary cast of each articulated specimen. The maxillomandibular relationship among the articulated scans did not change with this modification; only the maxillary cast was altered. The articulated casts and the modified maxillary cast were obtained in STL file format. In the TRIOS4-IOS not corrected opening, TRIOS4-IOS corrected opening, i700-IOS not corrected opening, and i700-IOS corrected opening subgroups, the dental design program automatically opened the vertical dimension between the maxillary and mandibular scans of each articulated specimen until the occlusal collisions were eliminated. The modified articulated casts were obtained in STL file format.

The maxillomandibular relationships obtained in the reference and experimental files were analyzed by using a reverse engineering program (Geomagic Wrap, v.2021; 3D Systems). First, 6 markers were virtually situated on the reference scans of the buccal surfaces of the right and left central incisors, right and left canine, and right and left first molar. Thirty-six linear measurements of the maxillary and mandibular markers were computed. To replicate the same linear measurements on each articulated maxillary and mandibular specimen, the reference scans were superimposed on the experimental scans without changing the 3-dimensional position of the experimental scans; hence, the maxillomandibular relationship of the experimental scans was unchanged (Fig. 6). The markers of the reference scans were used as a reference to locate the markers on the experimental scans. Finally, the identical linear measurements were made.

As the CAD software program modified some specimens (TRIOS4-IOS not corrected trimming, TRIOS4-IOS corrected trimming, i700-IOS not corrected trimming, and i700-IOS corrected trimming subgroups), an additional measurement was performed to evaluate the volumetric changes obtained in the trimmed specimens. First, the maxillary digital scan obtained by using each IOS was aligned with the corresponding experimental

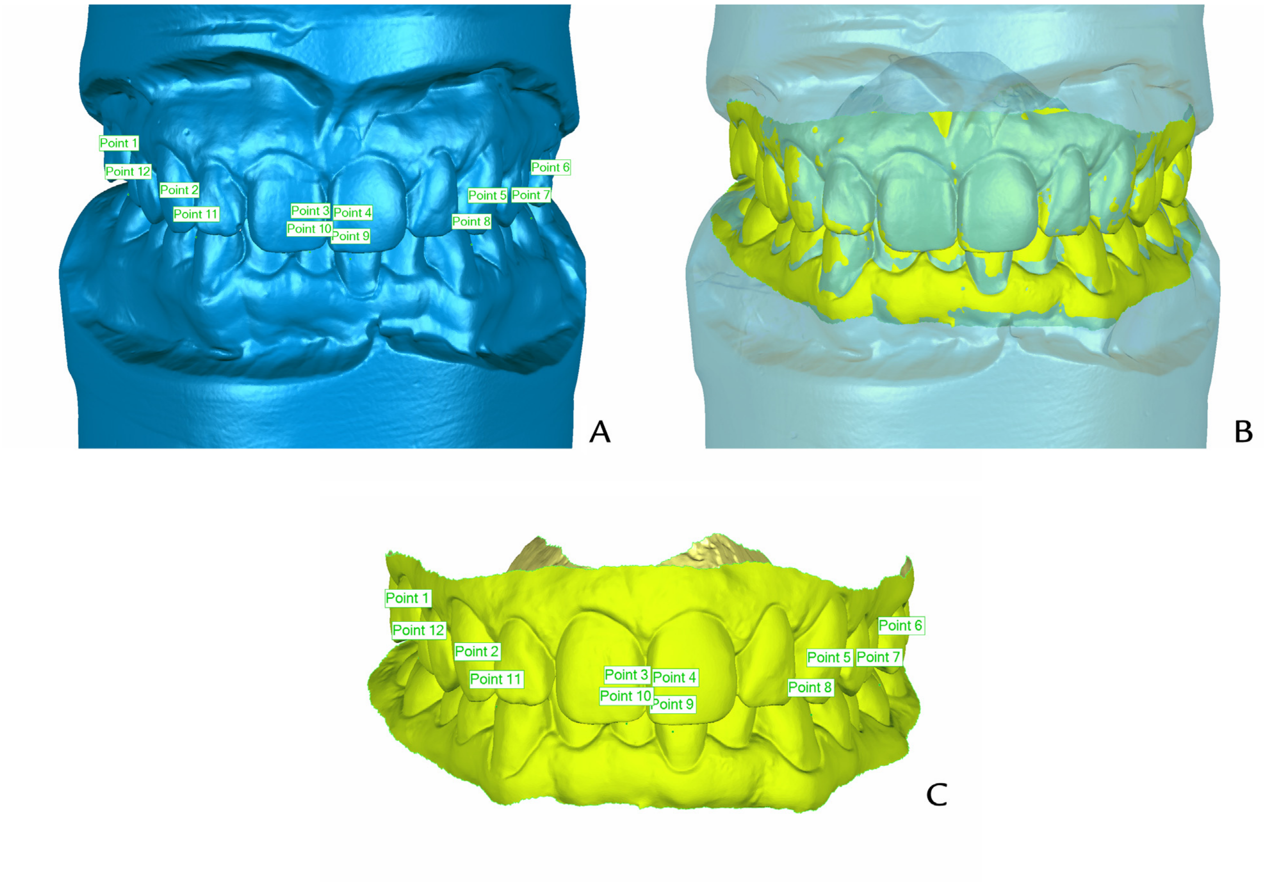


Figure 6. Representative procedures for analyzing maxillomandibular relationship. A, Markers placed on reference casts. B, Aligned reference casts and experimental intraoral digital scans. C, Markers transferred into experimental intraoral digital scans.

Table 1. Accuracy analysis of maxillomandibular relationship at MIP captured among subgroups tested

IOS	Group (Modification by Using the IOS Program)	Subgroup (Modification by Using the Dental CAD Program)	Trueness ±Precision (Overall Mean ±SD Measurement Discrepancies) (µm)
TRIOS4	IOS-not corrected	CAD-no changes	249 ±7
		Trimming	249 ±7
		Opening	212 ±8
	IOS-corrected	CAD-no changes	211 ±11
		Trimming	211 ±11
		Opening	211 ±11
i700	IOS-not corrected	CAD-no changes	211 ±21
		Trimming	211 ±21
		Opening	212 ±22
	IOS-corrected	CAD-no changes	169 ±31
		Trimming	169 ±31
		Opening	173 ±22

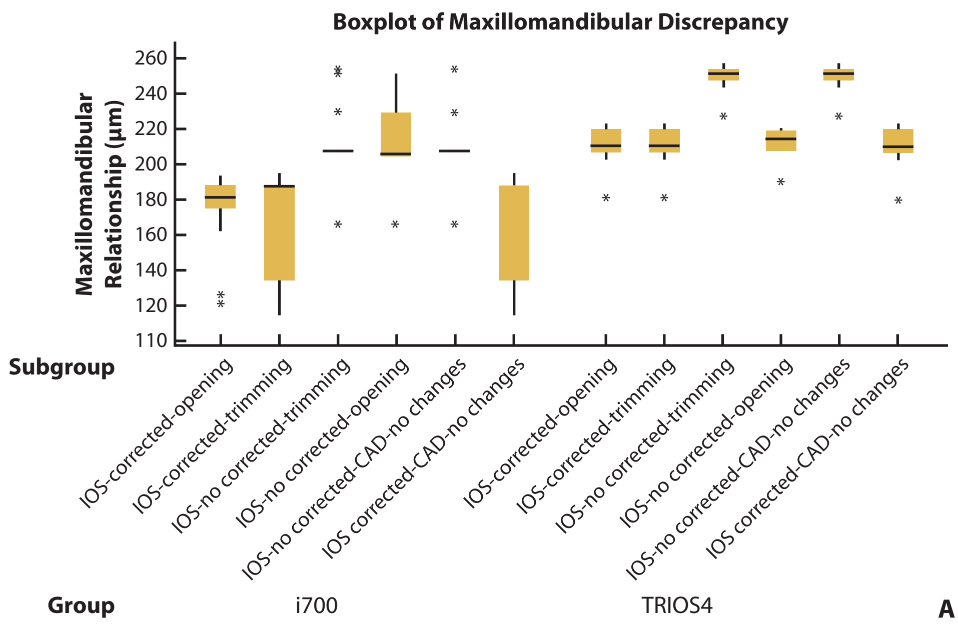
CAD, computer-aided design; IOS, intraoral scanner; MIP, maximum intercuspation position; SD, standard deviation. Trueness and precision mean values computed among groups tested.

intraoral digital scan (trimming subgroups) using the best fit technique. Secondly, the root mean square (RMS) error measurement was calculated using the following formula: $RMS = \sqrt{\frac{\sum_{i=1}^{n}(X_{1,i}-X_{2,i})^2}{n}}$, where $X_{1,i}$ are the reference data, $X_{2,i}$ are the scan data, and n designates the total number of measurement points computed in each evaluation.

Trueness was outlined as the average linear measurement or RMS differences between the reference and experimental files.[31] Precision was designated as the measurement disparities for each subgroup, for both linear measurements and RMS discrepancies.[31] The Shapiro-Wilk test showed that the interlandmark measurements and RMS data were normally distributed. Trueness was examined using 2-way ANOVA and pairwise multiple comparison Tukey tests (α=.05). Precision was evaluated using the Levene test (α=.05). RMS error discrepancies were investigated using 2-way ANOVA and pairwise multiple comparison Tukey tests (α=.05). Precision was evaluated using the Levene test (α=.05). Data were examined with a statistical software program (IBM SPSS Statistics, v25; IBM Corp).

RESULTS

Two-way ANOVA showed that the IOS used (df=1, MS=0.048367, F=177.39, *P*<.001) and the program



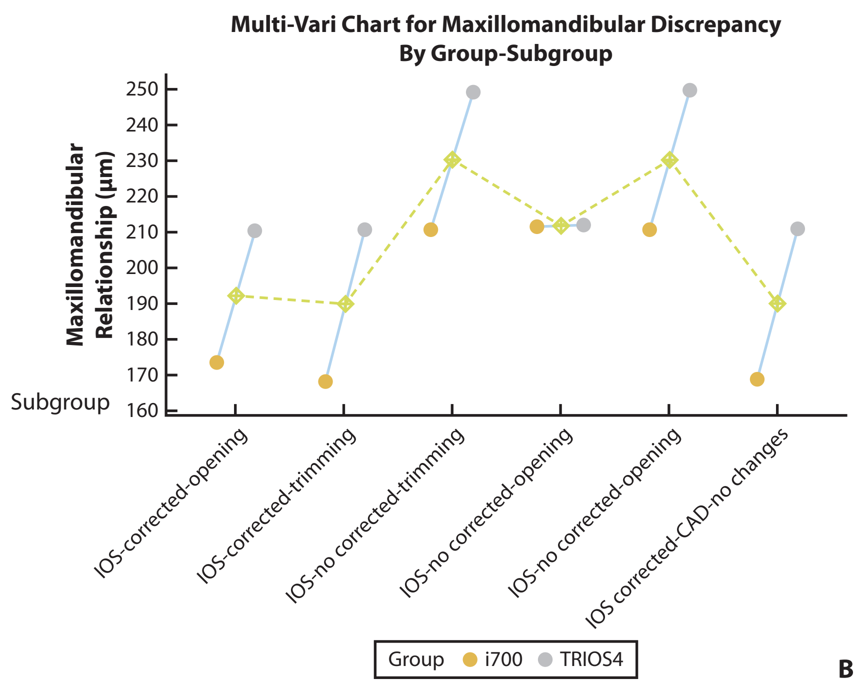
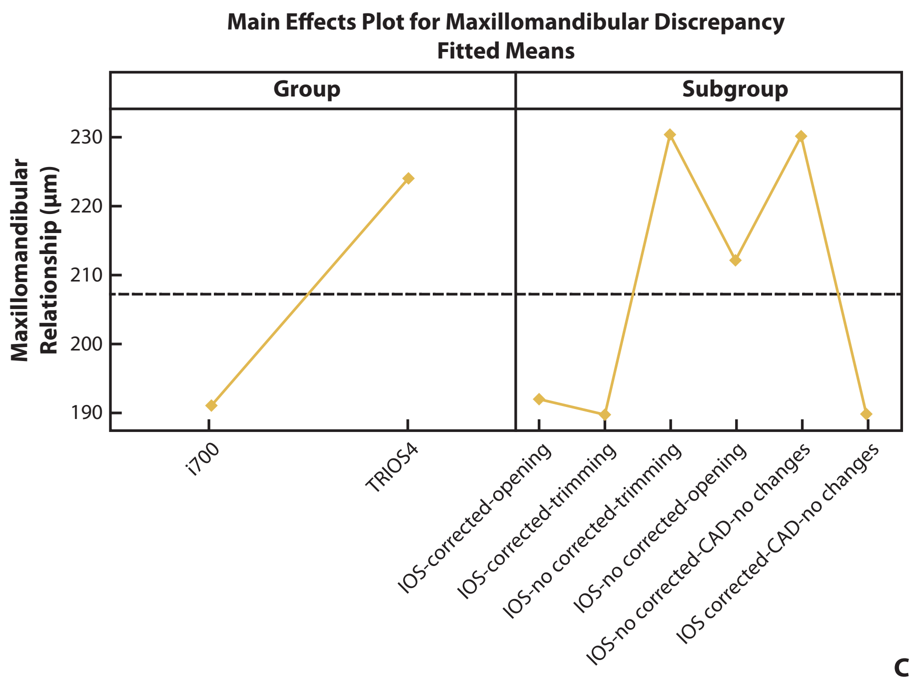


Figure 7. A, Boxplot of overall maxillomandibular discrepancies measured among subgroups tested. *Significantly different ($P<.05$). B, Multi-Vari chart for overall maxillomandibular discrepancies measured among subgroups tested.

corrections (df=14, MS=0.001279, F=4.69, $P<.001$) were significant factors in the trueness of the maxillomandibular relationship obtained (Table 1, Fig. 7). Significant interactions were found between IOS×IOS/CAD corrections (df=5, MS=0.001938, F=7.11, $P<.001$). Regarding the IOS factor, the Tukey test revealed that the i700 obtained higher trueness than the TRIOS4 ($P<.001$). Regarding the subgroup factor, the Tukey test showed



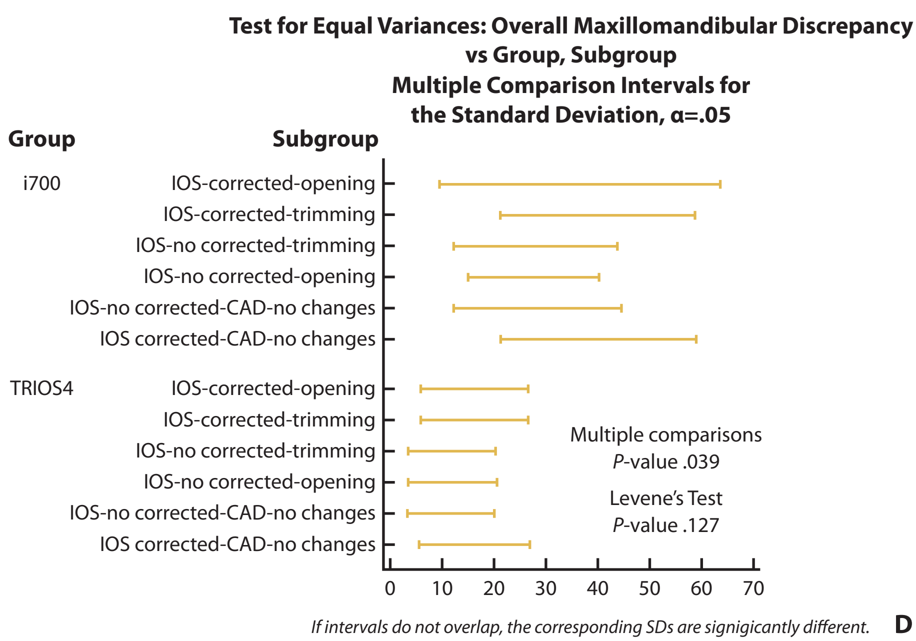


Figure 7. (*Continued*) C, Main effects plot for overall maxillomandibular discrepancies measured among subgroups tested. D, Test for equal variances for overall maxillomandibular discrepancy versus group, subgroup. Multiple comparison intervals for SD. CAD, computer-aided design; IOS, intraoral scanner; SD, standard deviation.

significant mean value discrepancies between the IOS and CAD corrections. The IOS-not corrected-CAD-no-changes and IOS-not corrected-trimming subgroups obtained the worst trueness among the subgroups tested (*P*<.001), while the IOS-corrected-CAD-no-changes, IOS-corrected-trimming, and IOS-corrected-opening subgroups showed the best trueness values among the subgroups tested (*P*<.001). The Levene test showed no significant differences in overall mean discrepancy SDs among the subgroups tested (*P*<.001) (Fig. 7D).

Regarding the RMS discrepancies, the 2-way ANOVA indicated significant mean RMS error differences among the subgroups tested (Table 2, Figs. 8, 9), with a significant interaction between Group×Subgroup (df=1,

Table 2. RMS error discrepancies measured among maxillary intraoral digital scan obtained by using each IOS tested and specimens of trimmed subgroups (TRIOS4-IOS not corrected trimming, TRIOS4-IOS corrected trimming, i700-IOS not corrected trimming, and i700-IOS corrected trimming subgroups)

IOS	Group (Modification by Using IOS Program)	Subgroup (Modification by Using Dental CAD Program)	Trueness ±Precision (RMS Error Mean ±SD) (µm)
TRIOS4	IOS-not corrected	CAD-no changes	Not applicable
		Trimming	12 ±1
		Opening	Not applicable
	IOS-corrected	CAD-no changes	Not applicable
		Trimming	4 ±1
		Opening	Not applicable
i700	IOS-not corrected	CAD-no changes	Not applicable
		Trimming	10 ±7
		Opening	Not applicable
	IOS-corrected	CAD-no changes	Not applicable
		Trimming	4 ±1
		Opening	Not applicable

CAD, computer-aided design; IOS, intraoral scanner; RMS, root mean square; SD, standard deviation.

MS=0.000844, F=69.02, *P*<.001). The IOS-not corrected-trimmed subgroups obtained a significantly higher RMS error discrepancy than the IOS-corrected-trimmed subgroups (*P*<.001). The Levene test indicated a significant difference in RMS precision (SD) among the IOS systems across the subgroups tested (*P*<.001).

DISCUSSION

The results of this clinical investigation indicated that the occlusal collision corrections performed by using either the IOS or CAD programs tested influenced the trueness of the maxillomandibular relationship at MIP; however, no differences were measured in the precision of the recorded maxillomandibular relationship. Therefore, the null hypothesis was partially rejected. The authors are unaware of investigations that have examined the influence of the occlusal collision corrections performed by IOSs or CAD programs on the accuracy of the virtual maxillomandibular relationship at MIP position recorded using IOSs. Therefore, comparisons with previous investigations were not possible.

Intraoral scanning technology influences the accuracy of the virtual maxillomandibular relationship recorded using these digitizing IOS systems.[5,8,9,11] The results of the present investigation were consistent with those of these previous investigations; the i700 system obtained higher trueness for the maxillomandibular relationship at MIP than the TRIOS4 device. Additionally, the scanning accuracy discrepancies between the IOSs assessed may have influenced the results acquired. In the present study, only these two IOSs were selected, as these were the only IOSs that allowed the selection of occlusal adjustment correction with the IOS software program. Further investigations are needed to assess the presence of occlusal collisions on the articulated intraoral digital scans and the accuracy of the maxillomandibular relationship obtained by using these alternative IOS systems.

Occlusal collisions were found in all the articulated intraoral digital scans at MIP captured with the two IOSs tested. Even if corrected using the IOS programs, the CAD dental program still detected occlusal collisions. However, the trueness of the maxillomandibular relationship obtained using the tested IOSs was better than the dental design program corrections when the occlusal collisions were adjusted using the IOS program. Additionally, the CAD corrections (trimming and opening) did not improve the results of the IOS program, and the trimming option caused volumetric changes on the occlusal surfaces of intraoral scans. Therefore, the occlusal adjustments of the articulated intraoral scans should be removed during the postprocessing procedures performed by either of the IOSs tested. These occlusal collision corrections were automatically performed by the IOS software program without any operator intervention. However, as the linear measurement discrepancies among the subgroups tested did not exceed 45 µm, the clinical implications may not be relevant. The clinical implications of the discrepancies of the maxillomandibular relationship captured are unclear, as is whether these discrepancies may affect diagnosis procedures or the occlusal contacts of dental restorations designed using a complete digital workflow. Clinical investigations are indicated to analyze the movements or adjustments completed by the software program of the IOSs tested, as well as the clinical implications of the distortions created by IOSs or CAD software program corrections on the accuracy of the recorded maxillomandibular relationship.

Data acquisition techniques are fundamental to IOS accuracy. In the present study, data capturing procedures were controlled as much as possible to reduce the variables that can impact the accuracy of the IOSs. Ambient lighting and relative humidity conditions were standardized, the IOSs were calibrated, the recommended scanning pattern provided by the IOS manufacturer was selected, and rescanning procedures were avoided. Additionally, the selected participant was completely dentate without dental restorations or interdental spaces. Additional studies assessing the accuracy of maxillomandibular relationships recorded using IOSs under different clinical situations and scanning conditions are recommended.

Limitations of the present clinical study included the limited clinical conditions tested (completely dentate scenario) and the use of a desktop scanner to obtain the reference data. Additional studies are required to further recognize the factors that can influence the accuracy of

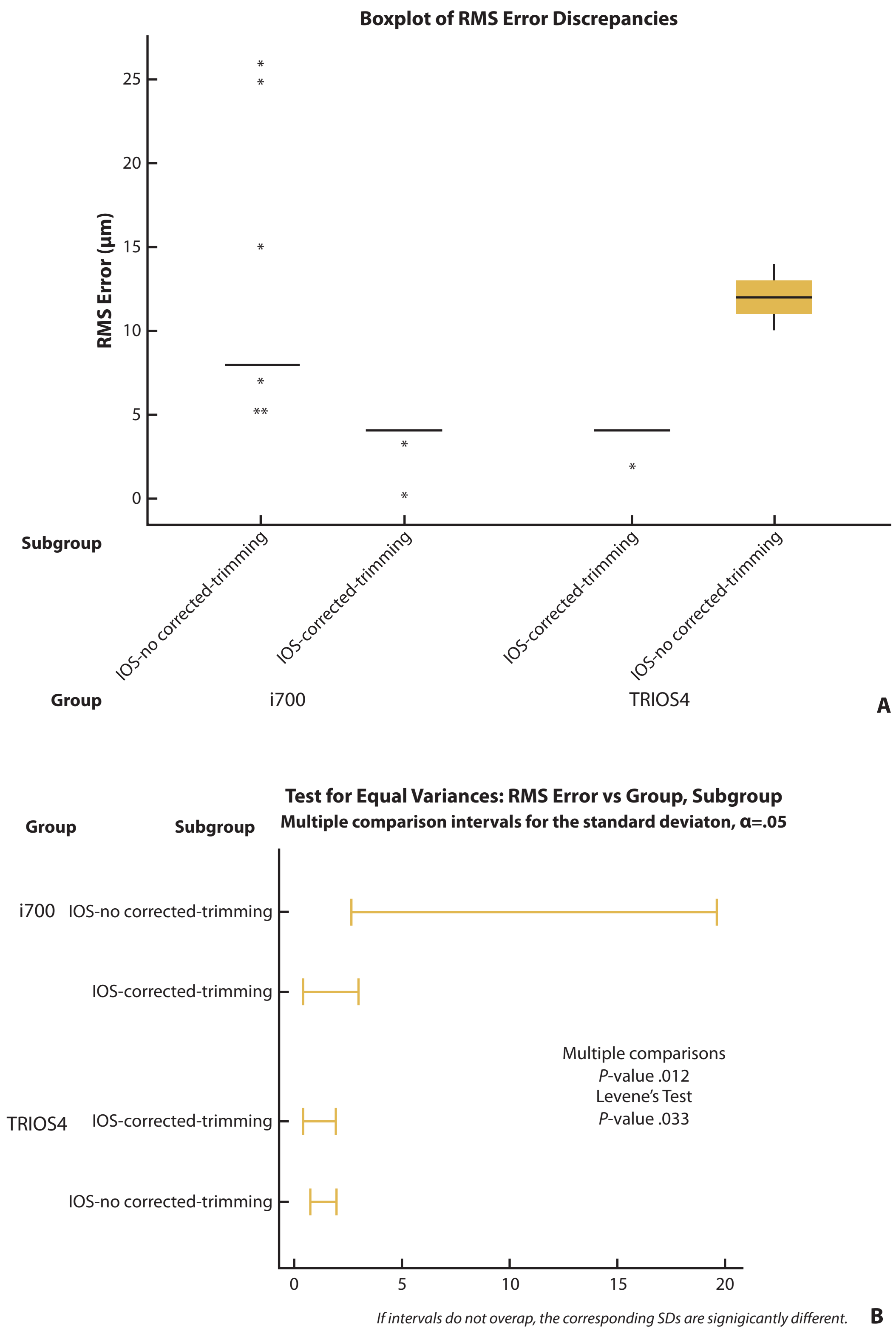


Figure 8. A, Boxplot of RMS error discrepancies. *Significantly different ($P<.05$). B, Test for equal variances for RMS error discrepancy versus group, subgroup. Multiple comparison intervals for SD. IOS, intraoral scanner; RMS, root mean square; SD, standard deviation.

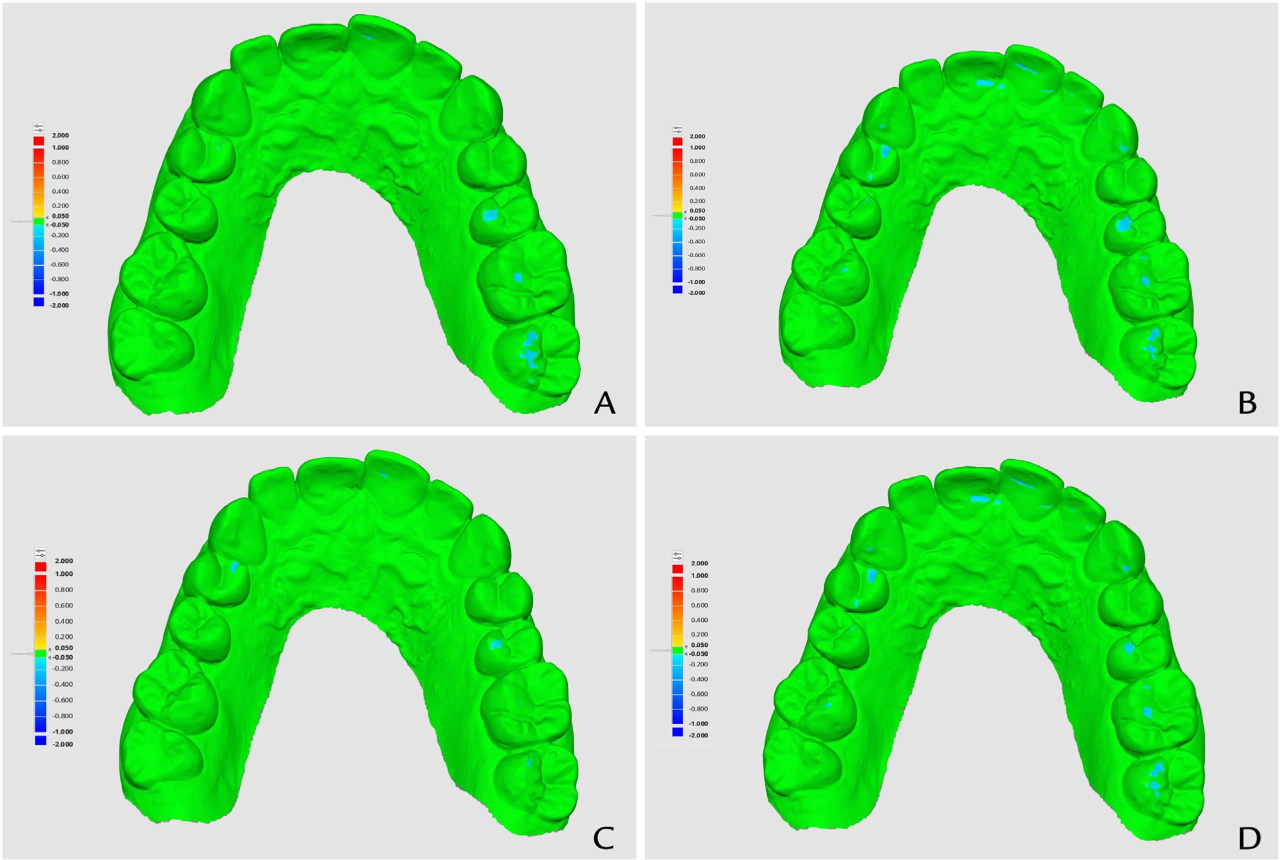


Figure 9. Representative color map discrepancies measured in trimming subgroups. A, TRIOS4-IOS-not corrected-trimming subgroup. B, TRIOS4-IOS-corrected-trimming subgroup. C, i700-IOS-not corrected-trimming subgroup. D, i700-IOS-corrected-trimming subgroup. IOS, intraoral scanner.

the virtual maxillomandibular relationship obtained by using IOSs.

CONCLUSIONS

Based on the findings of the present clinical study, the following conclusions were drawn:

1. The trueness of the maxillomandibular relationship at the MIP recorded was affected by the IOS used and the program used to correct the occlusal collisions of the articulated intraoral digital scans. However, no differences were found in the precision mean values of the maxillomandibular relationship at the MIP recorded in the subgroups tested.
2. The trueness of the maxillomandibular relationship at the MIP obtained using the tested IOSs was better when the occlusal collisions were adjusted using the IOS program than with the dental design program corrections.
3. The CAD program corrections (trimming and opening) did not improve the results of the IOS software program. Additionally, the trimming option caused volumetric changes on the occlusal surfaces of intraoral scans.

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