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Original Article

Accuracy of intraoral scanners in maxillary multiple restorations: An *in vitro* study

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Abstract *Background/purpose:* The accuracy of intraoral scanners (IOSs) plays a crucial role in the success of final restorations in digital workflows. Previous studies have shown that numerous factors affect the accuracy of IOSs. Most studies have evaluated the accuracy of IOS under one restoration condition. Therefore, the aim of this study was to evaluate the accuracy of two IOSs with different data acquisition methods across multiple restorations.
Materials and methods: A partially edentulous model with preparations were created and scanned using the laboratory scanner E4 as the reference model. Two IOSs, Trios 3 and Virtuo Vivo, were used in this study. Each scan was performed in same scanning strategy. Trueness and precision of each scan was compared by surface-matching software, and the data were statistically analyzed.
Results: Trios 3 showed no significant difference in trueness of full arch, single crown, and edentulous area, except for 3-unit bridge area than Virtuo Vivo ($P = 0.008$). However, Virtuo Vivo showed better precision than Trios 3 ($P = 0.003$). There was no differ in linear dental measurements between two scanners.
Conclusion: We found Trios 3 had better trueness in 3-unit bridge area compared to Virto Vivo, but there was no significant difference in the other preparation areas. While Virtuo Vivo showed better precision. Our results can provide insights for the selection of IOSs for various

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restorations in clinical practice. However, this is an *in vitro* study, the chairside challenges of IOSs should be considered.

Introduction

The application of computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies has led to rapid development of dental restoration fabrication workflows in past two decades.[1] The widespread use of CAD/CAM systems brings new challenges and goals for dentists. The dental CAD/CAM workflow can be divided into three steps: data acquisition of impressions, restoration design using digital software, and final restoration manufacturing.[2] To obtain a reliable impression is the first and most critical step in the success of prosthesis process. Instead of using conventional impressions with trays and materials or indirect digitalization via laboratory scanner, direct digitalization through optical impression with an intraoral scanner (IOS) is widely used in chairside recently.[3,4] The use of IOS provides time efficiency, eliminates potential errors due to deformation of elastic impression materials, improves patient acceptance and visualizes real-time images.[5]

Many commercially available IOSs have been developed by manufacturers to be faster, more accurate, and easier to handle. Both *in vitro* and *in vivo* studies have evaluated the accuracy of various IOSs in different conditions, such as single crown, bridges, complete or partially edentulous dentures, single or multiple implants.[6–10] According to the International Organization for Standardization (ISO), specifically ISO 5725, the term "accuracy" is consisting of trueness and precision. Trueness is defined as "the closeness of agreement between the arithmetic mean of a larger number of test results and the true or accepted reference value". Precision refers to "the closeness of agreement between test results obtained under stipulated conditions".[11] To measure trueness, a highly accurate industrial or laboratory scanner is commonly used to obtain reference impressions for *in vitro* studies.[12,13] Three-dimensional comparative analysis software programs using a best-fit alignment method have been employed in most research to superimpose digital impressions and evaluate deviations.[14]

Studies showed contradicting results regarding the accuracy of IOSs compared to conventional impressions or among different manufacturers.[4,6,7] These results are attributed to many factors, such as scanner type, acquisition technology, scan strategy, and associated software. Additionally, clinical factors including the presence of saliva and blood, patient movement, and clinician's experience, have also affected the accuracy of IOSs.[15] Although manufacturers and previous studies had provided guideline and scanning strategies to standardize and promote the accuracy, most research related to the accuracy of IOSs has been conducted by a single preparation condition only. The accuracy of new generation IOS is clinically important for achieving passive fit in restorations.

Therefore, this study was to investigate the accuracy of different IOSs systems in multiple restorations cases.

Materials and methods

Preparation of reference model

A partially edentulous maxillary typodont (Nissin Dental Products, Inc., Kyoto, Japan) was used as the reference model for the study. The missing teeth in the edentulous area were right central incisor, left central and lateral incisors, and left molars. The right second premolar and second molar were prepared for a 3-unit bridge and left first premolar was prepared for a single crown. The preparations were done by the experienced dentist according to the guidelines of crown and bridge preparation.

Collection of digital impressions

For the digital reference data, the prepared model was scanned by using a commonly used dental laboratory scanner (E4; 3Shape A/S, Copenhagen, Denmark). Two different IOSs, based on different acquisition technologies, were used in this study to investigate the trueness and precision. The Trios 3 (2.13.2.1, 3Shape A/S) is based on the confocal microscopy and ultrafast optical scanning technology, while Virtuo Vivo (3.1, Straumann, Basel, Switzerland) is based on blue laser multi-scan imaging technology. All scanners were calibrated according to the manufacturer's guidelines prior to scanning. The scans were performed ten times for each scanner. The scanning procedures outlined in the user manual and scan strategy were followed. The scan strategy (Fig. 1) was standardized for both scanners to compare the accuracy based on the reliable data set. The continuous scanning sequence with horizontal direction was used in this study. To control for variability, each scan was performed within a strict time limit of less than 120 s, and the distance between the scanning tip of IOS and the surface being scanned was maintained at a constant approximately 10 mm throughout the scanning process. In addition, all scans were operated in the same room with similar room temperature (22 °C), relative humidity (60%) and lighting conditions. All datasets from each scan were exported to a standard tessellation language (STL) file format for the standardization and subsequent analysis.

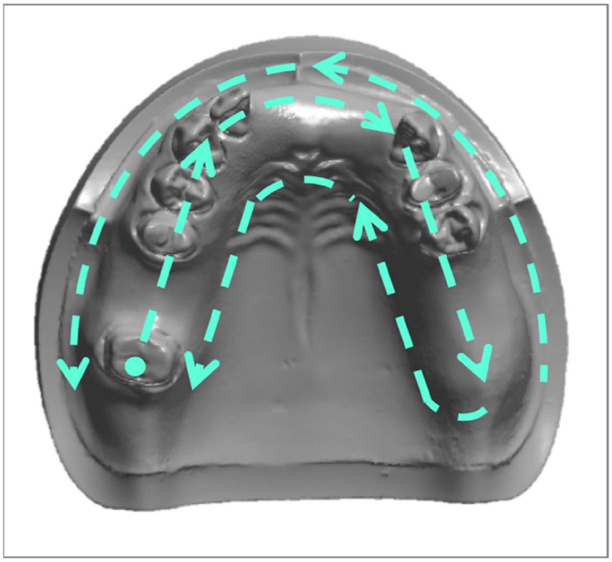

Figure 1 Scanning strategy used in the study.

Evaluation of the trueness and precision

STL files obtained by all scanner were imported to a surface-matching software (Geomagic Control X 2017, 3D Systems, Rock Hill, SC, USA) for three-dimensional analysis. The superimposition process was carried out by using best fit alignment alogrithm within the selected three points. For the trueness measurement, models from IOSs of each scan were superimposed to the model from reference scanner. For the precision measurement, one model with best trueness performance obtained from each scanner was chosen as the reference model to superimpose with the remaining nine models. The root mean square (RMS) value and color mapping feature were used for quantitative and visual evaluation. The RMS value, which represents the absolute dimensional difference between the experimental models and reference model, was automatically calculated by software.

To evaluate the reliability and validity, the STL files were imported into the 3D slicer software (Brigham and Women's Hospital, Inc., Boston, MA, USA) and the linear dental measurements were performed. The dimensions of the prepared teeth were measured using various parameters: the distance from the marginal line to the incisal edge on buccal (B) and palatal (P) sides, mesio-distal (MD) and bucco-palatal (BP) distance of the occlusal plane, the distance between prepared second premolar to second molar of 3-unit bridge at buccal (PMB) and palatal (PMP) cusp tips, and inter-distance between canines (CC). These parameters were compared to the reference data assessed manually from a reference model using an electronic Vernier caliper with an accuracy of 0.01 mm. All data was collected by the same examiners who repeated the procedure that measuring each parameter three times.

Statistical analysis

The data from the experimental analyses were described using means and standard deviations. The normality of data distributions was tested by the Kolmogorov-Smirnov test. Comparisons between two groups were analyzed using Mann-Whitney U test and *t* test. All statistical analyses were carried out using SPSS statistical software (IBM SPSS Statistics, IBM Corp, Armonk, NY, USA). Values of $P < 0.05$ were considered statistically significant.

Results

The measurement of trueness of the full arch among two groups, revealed the following results: Trios 3 scanner had a mean of 67.87 ± 12.69 μm, and Virtuo Vivo scanner had a mean of 71.35 ± 10.22 μm. There was no significant difference between the two scanners as shown in Fig. 2C.

Then, the single crown area, 3-unit bridge area, and canine to canine area were analyzed separately. The analysis of trueness in a single crown area scanned by Trios 3 and Virtuo Vivo scanner shows in the Fig. 3. Trios 3 group showed with a mean of 64.49 ± 11.17 μm, and Virtuo Vivo with a mean of 58.77 ± 7.91 μm.

The assessment of trueness in the bridge area was displayed in the Fig. 4. It showed significant difference between Trios 3 (91.21 ± 12.37 μm), and Virtuo Vivo (113.20 ± 16.60 μm), with $P = 0.008$.

The boxplot of trueness measurement in canine to canine area within two scanners (Fig. 5) shows the mean of Trios 3 at 47.90 ± 10.14 μm, and the mean of Virtuo Vivo at 46.19 ± 5.52 μm. No statistically significant difference was found between two scanners in the anterior edentulous area.

The precision of two scanners was shown in the Fig. 6. Trios 3 group had a mean of 112.86 ± 15.04 μm, and Virtuo Vivo group had a mean of 48.97 ± 27.54 μm. Comparisons

Table 1 Measurement of prepared teeth parameters for crown and bridge, the distance between intercanine.

(mm)	17B		17P		17BP		17MD		15B		15P		15BP	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lab scanner	3.478	0.187	3.621	0.124	7.583	0.502	5.731	0.124	5.667	0.154	4.546	0.112	6.023	0.260
Manual	3.543	0.072	3.667	0.150	7.567	0.201	5.787	0.078	5.333	0.126	4.507	0.060	5.963	0.131
Trios 3	3.720	0.152	3.697	0.089	7.280	0.143	5.771	0.089	5.640	0.161	4.537	0.156	5.816	0.113
Virtuo Vivo	3.380	0.136	3.617	0.088	7.623	0.180	5.857	0.147	5.652	0.317	4.462	0.092	6.070	0.172

B: the distance from the marginal line to incisal edge on buccal side, P: the distance from the marginal line to incisal edge on palatal side, BP: bucco-palatal distance of occlusal plane, MD: mesio-distal distance of occlusal plane, PMB: the distance between prepared second premolar to second molar of 3-unit bridge at buccal cusp tips, PMP: the distance between prepared second premolar to second molar of 3-unit bridge at palatal cusp tips, CC: inter-distance between canines.

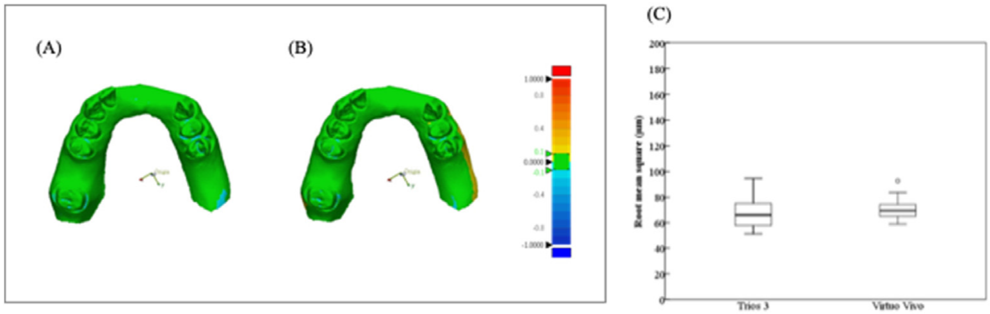

Figure 2 Surface matching color map of trueness in full arch scan of (A) Trios 3 and (B) Virtuo Vivo. (C) Boxplot of superimposition of reference scan among different scanners.

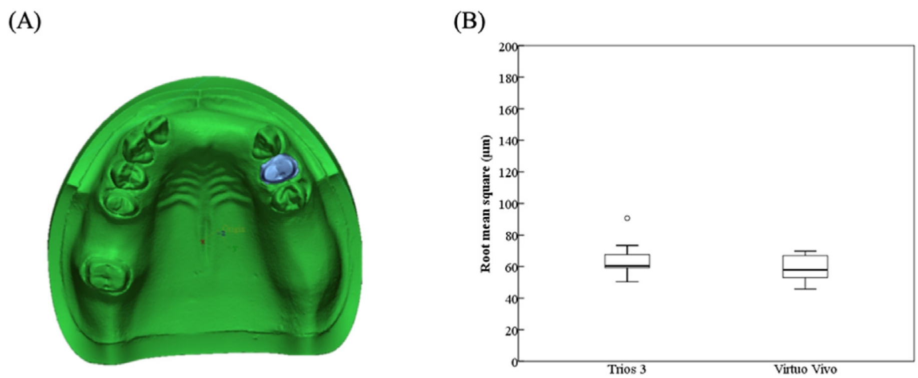

Figure 3 (A) The trueness evaluation of segmental surface matching color map in single crown area. (B) Boxplot of superimposition to reference scan in Trios 3 and Virtuo Vivo.

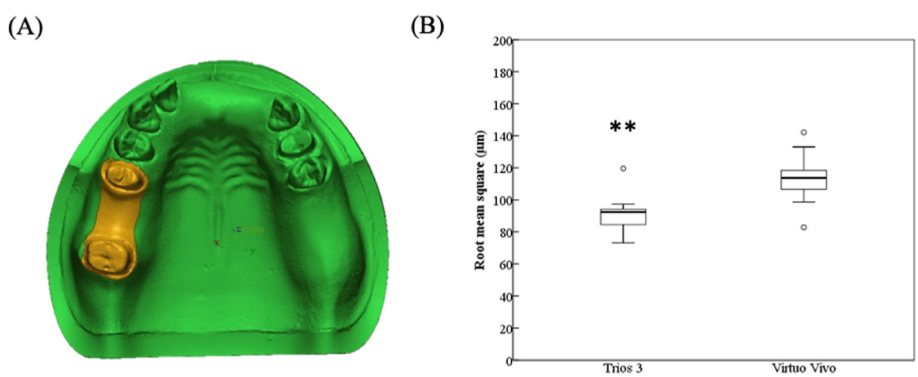

Figure 4 (A) The trueness evaluation of segmental surface matching color map in 3-unit bridge area. (B) Boxplot of superimposition to reference scan in Trios 3 and Virtuo Vivo. **: $P < 0.01$.

15MD		PMB		PMP		24B		24P		24BP		24MD		CC	
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
3.436	0.062	18.257	0.133	17.300	0.272	6.137	0.271	4.261	0.329	6.652	0.202	3.692	0.057	30.483	0.250
3.710	0.165	18.307	0.287	17.707	0.085	6.263	0.038	4.063	0.090	6.670	0.108	3.733	0.119	30.363	0.031
3.574	0.105	18.148	0.151	17.427	0.186	6.127	0.114	4.067	0.057	6.589	0.091	3.703	0.106	30.449	0.073
3.659	0.104	18.432	0.091	17.562	0.287	6.113	0.218	4.072	0.107	6.649	0.172	3.729	0.095	30.350	0.133

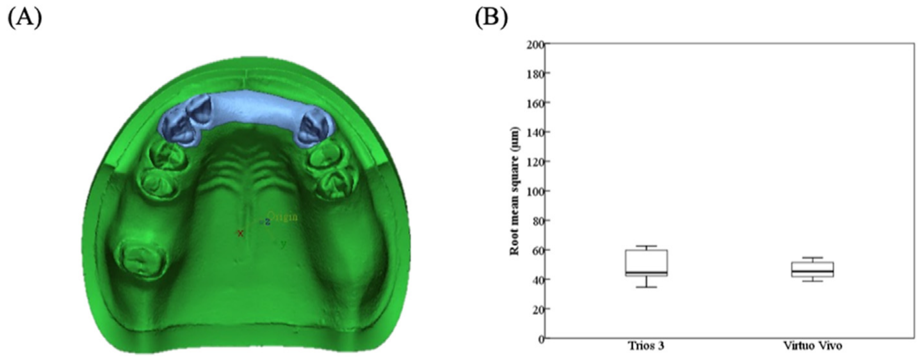

Figure 5 (A) The trueness evaluation of segmental surface matching color map in canine to canine area. (B) Boxplot of superimposition to reference scan in Trios 3 and Virtuo Vivo.

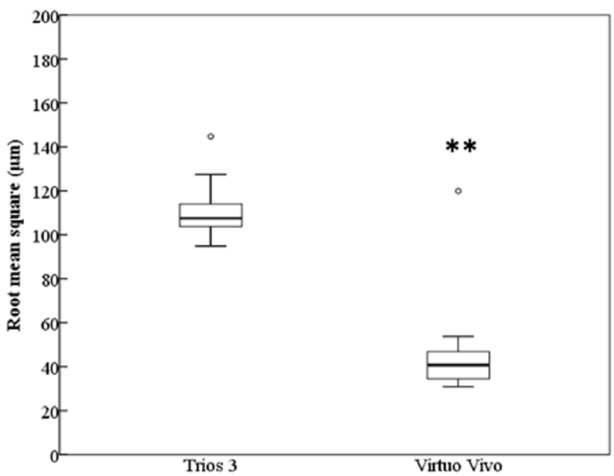

Figure 6 Boxplot of precision of full arch scan in TRIOS 3 and Virtuo Vivo. **: $P < 0.01$.

between Trios 3 and Virtuo Vivo groups revealed statistically significant differences, with $P = 0.003$.

After measuring the distance between points on the reference model manually with an electronic Vernier caliper and digitally by using 3D slicer software, there was no significant difference between manual and digital measuring methods (Table 1). In measurement of CC, the result showed nearly the same means of approximately 30 mm in each scanner. The mean value of the distance from the prepared second premolar to the second molar of a 3-unit bridge at the buccal (PMB) and palatal (PMP) cusp tips showed nearly the same value of approximately 18 mm and 17 mm respectively. However, the SD of the manual group in PMP is smaller than that of digital groups while the values of SD of PMB are nearly the same. The statistical analysis of the measurements between manual and digital methods had no significant difference in all parameters.

Discussion

The aim of the present study was to evaluate the accuracy of two different IOS systems on a model with multiple restorations. Based on the results of the present study, there were no statistically significant differences in trueness between Trios 3 and Virtuo Vivo of the full arch, single prepared crown and anterior edentulous areas, except for the segmental 3-unit bridge, Trios 3 showed better trueness ($P = 0.008$). Additionally, Virtuo Vivo showed better precision ($P = 0.003$).

Nowadays, digital workflows for restorations have changed the daily procedures in clinical practice compared to conventional workflows. Thanks to the development of CAD/CAM technologies, restorations can be fabricated rapidly and easily.[1] In addition, digital impressions at chairside leads to more predictable results, allowing for real-time adjustment to impressions or prepared tooth areas. Therefore, the accuracy of impressions plays a pivotal role in digital workflows. To improve and optimize impression image capture and digitalization in chairside, there are many IOSs available on the market, featuring various devices and innovations among the manufactures.

In our study, Trios 3 and Virtuo Vivo were used for accuracy evaluation. Trios 3 is a structured light scanner that uses confocal microscopy and ultrafast optical scanning technology. It can capture more than 3000 two-dimensional images per second and then combines up to 1000 3D digital pictures.[7] Virtuo Vivo uses blue laser-multiscan imaging technology. Most studies compared the accuracy of Trios 3 with other IOSs due to its widespread use in the market. However, there have been fewer studies investigating the accuracy of Virtuo Vivo as it was recently introduced.

Diker and Tak reported the comparison of accuracy among different IOSs, including Trios 3 and Virtuo Vivo, for single prepared crown,[16] complete-arch and 4-unit fixed partial dentures.[17] The trueness and precision results in that studies are similar to our study. Although both studies showed no statistically significant difference in trueness, they demonstrated lower deviations in trueness of Trios (48.5 ± 8.25 μm) and Virtuo Vivo (59 ± 5.75 μm) in complete-arch scan.[17] The trueness may vary between different preparations of complete or partial arch scans due to the features of preparations. Although our results have shown that the trueness differed between the two scanners in the 3-unit bridge, all scan results obtained from both groups were within a clinically acceptable threshold (up to 200 μm) or a digitally acceptable threshold (below 120 μm).[19,20] Additionally, their studies on single prepared crown studies showed a statistically significant difference in precision, with lower deviation in precision of Trios 3, which differs from our results.[16,17] This deviation may due to variations in IOS versions, as we used the newest Virtuo Vivo scanner in our study.

For each IOS, the scanning strategy is specified by the manufacturer. Previous studies have shown that the accuracy of IOSs is affected by different scan strategies, especially in complete-arch scans.[16,18] In our study, we performed a commonly used scan strategy in both IOSs to minimize variation in the scanning procedure. The scan was started from the occlusal side of the right molars, moving across the palatal, buccal, distal, and mesial side of preparations to the left molars, then continued the buccal side in reverse direction and toward the palatal side. This scanning strategy is same as scan strategy recommended by Trios 3.

Since this is an *in vitro* study, additional challenges present in chairside were not simulated, such as saliva, presence of the tongue. For this reason, the further training of IOS is needed. Several studies showed that with repeated scanning experience and clinical experience can obtain better accuracy and more effective clinical applications.[21,22]

In summary of our study, the trueness may vary among restorations areas, particularly in prepared bridges. We found no significant difference in trueness between Trios 3 and Virtuo Vivo in full arch, single crown and anterior edentulous areas. In addition, Virtuo Vivo exhibited better precision. Taken together, this information can provide insights for the selection of IOSs for various restorations in clinical practice. However, there were only two types of IOS used in this *in vitro* study, our recent findings may not fully represent the wide variety of IOS. More advanced IOS are developing and numerous IOS options are available on the market, further *in vivo* studies in clinical situations should be considered.

Declaration of competing interest

The authors have declared that there are no competing interests.

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