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Original Article

Accuracy comparison of scan segmental sequential ranges with two intraoral scanners for maxilla and mandible

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Abstract *Background/purpose:* The accuracy of a full-arch scan by using an intraoral scanner should be validated under clinical conditions. This study aimed to compare the accuracy of full-arch digital impressions in the maxilla and mandible using two intra oral scanners with three different scan segmental sequential ranges.

Materials and methods: A dental model with 28 teeth in their normal positions served as the reference. Sixty full-arch scans were performed using Trios 3 and Trios 4, employing scanning strategy O (manufacturer's original method), OH (segmental sequential ranges one half), and TQ (segmental sequential ranges third quarter). Trueness was evaluated by comparing digital impressions with a reference dataset using specialized software. One-way ANOVA and Tukey tests assessed differences between the groups.

Results: For Trios 3 on the maxilla, no significant difference was found among the groups of trueness; in the mandible, strategy O exhibited a significant difference ($P = 0.008$) with the highest deviation. For Trios 4 on the maxilla, strategy TQ demonstrated the lowest deviation with a significant difference ($P = 0.006$); in the mandible, no significant difference was found among the groups of trueness.

Conclusion: Strategy TQ exhibited the best trueness for Trios 3 and Trios 4, suggesting it may be preferred for higher accuracy. Clinicians should consider these findings when selecting scanning strategies and intraoral scanners for specific cases.

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Introduction

Intraoral scanning technology was first proposed in the 1980s.[1] After several decades of evolution and improvement in technology, dentists have widely accepted digital intraoral scanners.[2] Nowadays, optical scanners are widely used in orthodontic treatment, caries detection, prosthesis making, implant rehabilitation and full mouth reconstruction.[3–7] When performing oral scanning however, their accuracy is easily affected by different brands of systems, light sources, scanning methods, scanning time, oral environment and operators,[8,9] so avoiding environmental interference and obtaining more accurate measurement results has always been a topic of scholars' efforts.[10,11]

Ender et al.[12] compared the scan results of 8 different oral scanning systems on the maxilla's full and partial dental arches. Within the limitations of the study, they demonstrated that the digital impressions obtained by some oral scanning systems could effectively replace traditional partial arch impressions, although it appears still challenging to scan the complete structure.[13] The full-arch scan may present systematic deviations that transfer even further to the clinical situation. While the manufacturer provides information about the recommended method of performing the scan, the clinician will use specific equipment to learn and gain personal clinical experience in each new case,[5,6,14] although it can be seen from the previous studies that most of the comparisons are focused on different oral scanners, and the literature on the influence of various scanning methods of the same intraoral scanner on the accuracy of the full-arch scan is scarce.[15–17] Müller et al.[18] tried to use the Trios Pod scanner to scan the maxilla with three different paths (A, first buccal surfaces, return from occlusal-palatal; B, first occlusal-palatal, return buccal; C, S-type one-way), finding that among these three different methods, strategy B had the highest authenticity and accuracy in the full-arch scan, so scan strategies in Trios POD could minimize inaccuracies in the final reconstruction process.

Passos et al.[19] used 13 scan strategies to evaluate the trueness and precision of two scanners and found each individual scanner possesses its own scan strategy. Latham et al.[20] compared four scanners and 4 scan strategies, and also demonstrated that Trios had the fastest scan time but was also affected by scan patterns (strategies) in full arch scans, finding that a scanning pattern using special segmental sequential ranges and overlapping seemed to have the best combination of speed, trueness and precision. Al-Rimawi et al.[21] showed the lower full arch deviation of Trios was 120 $\pm$ 34 μm; Medina-Sotomayor et al.[22] evaluated the upper full arch and showed the deviation of trueness of Trios was 55.3 $\pm$ 8.7 μm while the precision of Trios was 194.5 $\pm$ 11.7 μm. Diker and Tak[23] showed the Trios had the best trueness for the complete arch, while Amornvit et al.[24] mentioned that in ten studied scanners, the trueness varied but the precision was favorably similar, especially when scanning the full arch where the dentist needed to take more caution in capturing a good scan pattern, finding that the Trios series showed the best scan results compared to other scanners. Oh et al.[25] showed in the deviation of full arch scan by the Trios series, the segmental scan (91.73 $\pm$ 5.85 μm) revealed no significant difference with a continual horizontal scan (87.60 $\pm$ 5.7 μm), while Karakas-Stupar et al.[26] compared five intraoral scanners and found the deviation of Trios 3 (16 $\pm$ 5 μm) was similar to that of Trios 4 (18 $\pm$ 3 μm), although Róth et al.[27] show the Trios 4 possessed superior accuracy over the Trios 3.

Yehia et al.[28] showed the deviations of maxilla full arch scan and found the 2nd molar area had higher deviations than 2nd premolar and canine areas, while Feng et al.[9] revealed that the 3D model reconstruction would cause larger deviations in the curved areas of the dental arch in areas including premolars, canines and the distal surface of the molars that require more angles to be flipped during shooting. Trios series are one of widely used intraoral scanners,[29] however, Trios 3 has not been eliminated because of the launch of the new Trios 4 in 2019. Moreover, Revell et al.[30] evaluated 5 intraoral scanners (IOSs) for complete-arch implant prosthesis, and the results showed that experience with intraoral scanners improved the accuracy of superimposition of a complete arch. Trios 3 would be better for inexperienced clinicians and Trios 4 for experienced ones.

However, the literature regarding the influence of different scan sequential ranges on the maxilla and mandible is scarce; consequently, this study aimed to compare the accuracy and precision of full-arch digital impression in maxillary and mandible by three different scan segmental sequential ranges using Trios 3 and Trios 4 devices in order to provide clinical operators with a more accurate scanning method.

Materials and methods

The Nissin dental models (Nissin Dental Products Inc., Kyoto, Japan) were used as the reference model, mounted on the dental chair to simulate clinical scanning position. The reference models were scanned by desktop scanner (E4 Dental Scanner; 3 shape, Copenhagen, Denmark). The Trios 3 and Trios 4 scanners (3 shape) were part of a confocal IOS system used in this study, calibrated using the manufacturer's guidelines. One with at least seven years of clinical-experienced right-handed dentist performed all scans, and one arch scan was controlled for 1200 sheet images, while the scan time of one arch was controlled under 60 s. The scanning oral environment was set to be dried under similar room temperatures (22 °C), relative humidity (60%) and room light.

Three scanning strategies were set up in this study, and ten scans were performed for each scan sequential ranges. The G power analysis was used to estimate the required sample size, assuming three test groups, an effect size of 0.45, the probability of Type I error of 0.05, and the power of 0.95. The sample size was 60, thus determined to be 10 per group. The schematic diagram is shown in Fig. 1. The first strategy (strategy O) was started from tooth 17 occlusal surface and proceeding to tooth 27, returning via the palatal surface, then finally scanning the buccal surface. The mandibular line path started from tooth 37 occlusal surface, proceeding longitudinally along the arch

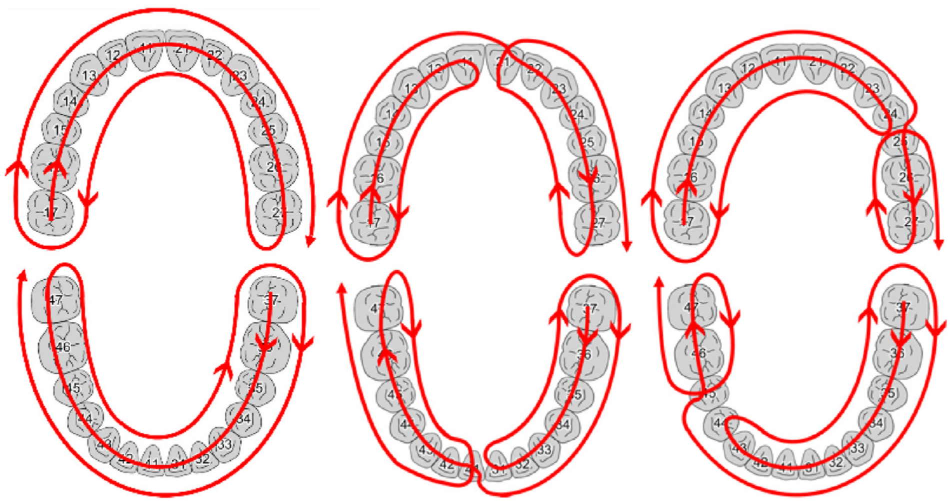

Figure 1 The three scanning strategies conducted by the Trios 3 device. ((*Left*) strategy O, (*Middle*) strategy OH and (*Right*) strategy TQ).

and ending at tooth 47, then continuing on the lingual side and finally, the buccal side.

The second scan strategy (strategy OH) was started from tooth 17 occlusal surface toward quadrant II, then turned back at 21 through the palatal side and scanning continued to 17 buccal side. Next, the scan overturned at 21 from buccal to II quarter occlusal surfaces, proceeding to 27 and returning to the palatal surface and back to 21 palatal side, then overturned to buccal side of II quarter, finally ending at 27 buccal side. The mandibular line path started from tooth 37 occlusal surface, then turned back at 31 through the lingual side and continued scanning to 37 lingual side. Next, the scan flipped to 37 buccal, proceeded to 41, then flipped to quadrant IV occlusal side. Finally, the scan flipped at 47 through the lingual to 41 lingual side and overturned to the labial side then quadrant IV buccal side and ended at 47 buccal side.

The last strategy (strategy TQ) was started from tooth 17 occlusal surface toward quadrant II, then turned back from 24 through the palatal side and continued scanning to 17 palatal side. Next, the scan head flipped from the palatal side to the buccal side at 27 and continued to scan the buccal side to 24; the scan then overturned at 24 from buccal to occlusal surfaces, proceeded to 27 and returned to the palatal surface, then back to 24 palatal side, then overturned to the buccal surface, and finally ended at 27 buccal side. The mandibular line path started from tooth 37 occlusal surface, then turned back at 44 through the lingual side and continued scanning to 37 lingual side. Next, the scan flipped to 37 buccal, proceeded to 44, then flipped to quadrant IV occlusal side. After that, it, proceeded to 47 and flipped at 47 through the lingual side to 41 and overturned to the labial side and ended at 47 buccal side.

The three scan strategies were performed by Trios 3 and Trios 4, and 120 scan files were recorded and superimposed with the file from reference scanner. The CAD software (exocad DentalCAD; exocad GmbH, Align Technology Inc., Santa Clara, CA, USA) was used to calculate the maximum deviations of each tooth position. Use of the Trios 3 and 4 intraoral scanners to scan the mandible with the three different scanning strategies and the maximum deviation compared to the reference model is shown in Fig. 2 (green line represents the reference model, orange line indicates the scanning results by the oral scanners). One-way ANOVA was used to test the variance for the test group and the Tukey test via IBM SPSS (SPSS Statistics for Windows, v20; IBM Corp., Armonk, NY, USA). A statistical significance value of $P < 0.05$ was used in all tests.

Results

Fig. 3 shows the superimposition deviations between the three scanning strategies using Trios 3 and Trios 4 on the maxilla (Fig. 3a) and mandible (Fig. 3b). Different paths of strategy show similar trend of deviations for each device. For Trios 3 (blue line), strategy O shows the deviations between 75 and 350 μm, and there is a peak increase at the 17, 21, 24 and 27. Strategies OH and TQ show similar trends here revealing significant changes in 11, 24, and 27 positions. The deviations between these three scanning strategies in the upper right side are relatively stable (<150 μm); however, when scanning middle and upper left sides, the difference value apparently increases. It can even be nearly three times worse, indicating that the scanning result at the upper right is more accurate and precise than that in the upper left in Trios 3.

Fig. 3a shows the deviation of Trios 4 (red line) of three different scanning strategies was higher on both sides (17, 27) and lower in the middle (11, 21). Three different scanning strategies show the deviation between 75 and 270 μm. Strategy O shows lowest deviation 230 μm at tooth 17; strategy TQ shows lowest deviation 75 μm at tooth 11 and the lowest deviation 150 μm at tooth 27.

In Fig. 3(b), deviations from Trios 4 (red line) at mandible were always higher than Trios 3. The mean deviation's range was from 93 μm to 430 μm. Strategy TQ had lowest deviation 100 μm at tooth 41 and strategy OH had the highest deviation 350 μm at tooth 47.

Comparing the scanning results of the maxilla and mandible, the latter showed better precision than the former (Fig. 4), with results indicating that peak trueness value occurred at different tooth positions, meaning that different scanning methods could be selected for the maxilla and mandible to obtain the best results.

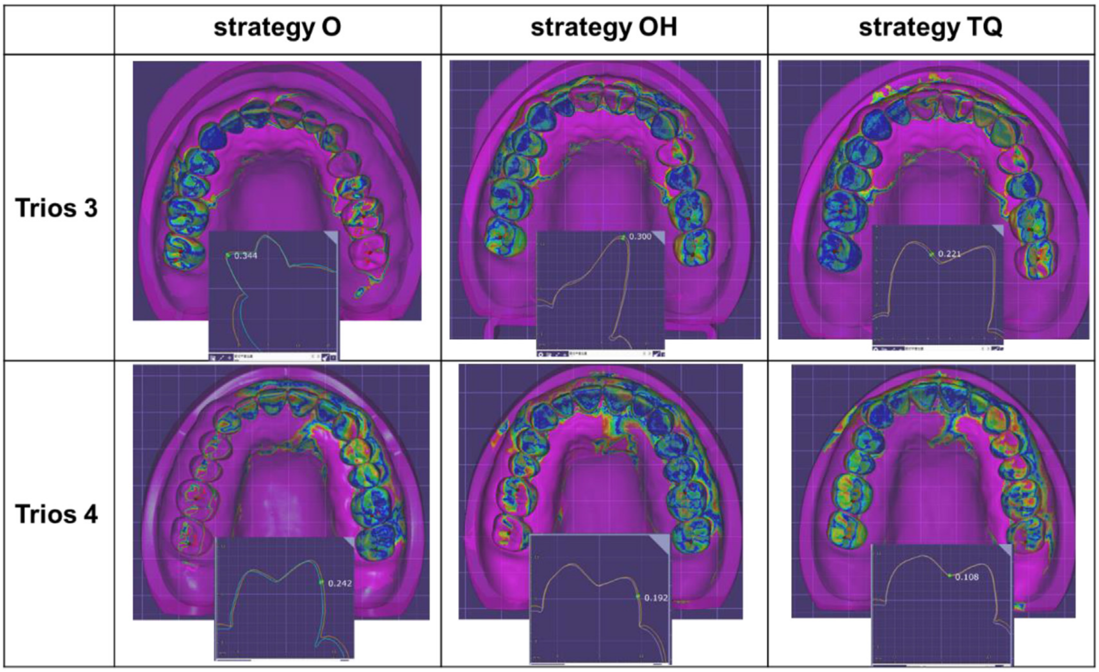

Figure 2 Superposition and measuring point showing deviations for scanning with different strategies and scanners compared to the reference model. (green line represents the reference model, orange line indicates the scanning results by the oral scanners.).

Table 1 shows the maximum deviation of trueness of Trios 3 and Trios 4 for maxilla. For Trios 3 on the maxilla, the trueness ranged from 131 ± 90 μm for strategy OH, 123 ± 87 μm for strategy TQ, and 140 ± 120 μm for strategy O. No significant differences among the three groups in the maxilla ($P = 0.387$) were found. On the other hand, the values of 78 ± 33 μm for strategy OH, 84 ± 38 μm for strategy TQ, and 90 ± 32 μm for strategy O in the mandible part were found (see Table 2). Strategy OH showed significant difference ($P = 0.008$) and the lowest deviation. The calculations revealed statistically significant difference of precision for different scanning strategies at the maxilla part ($P = 0.046$) although no difference among the lower group ($P = 0.073$) was found.

For Trios 4 on the maxilla, the trueness ranged from 115 ± 84 μm for strategy OH, 104 ± 75 μm for strategy TQ, and 138 ± 110 μm for strategy O. The lowest deviation was strategy TQ and significant difference was observed among the three strategies ($P = 0.006$). On the other hand, in the values of 193 ± 103 μm for strategy OH, 184 ± 100 μm for strategy TQ, and 174 ± 98 μm for strategy O for the mandible part, no significant difference was observed among the three strategies ($P = 0.281$). The calculation revealed no statistically significant difference of precision for different scanning strategies at the maxilla part ($P = 0.073$). Still, a statistical difference of precision ($P < 0.001$) was shown at the mandible side.

Discussion

The aim of the study was to compare the accuracy of two intraoral scanners, namely Trios 3 and Trios 4, when used to scan different segments of the maxilla and mandible in a sequential manner. In terms of trueness, Trios 3 exhibited similar performance across various scanning strategies in the maxilla; however, in the mandible, the OH strategy yielded the lowest deviation ($P = 0.008$) but no significant difference between strategy OH and TQ. On the other hand, Trios 4 demonstrated the lowest deviation in the maxilla when using the TQ strategy ($P = 0.006$), but no significant differences in trueness were observed among the three strategies employed in the mandible. Furthermore, the precision range of Trios 4 was lower than that of Trios 3, as illustrated in Fig. 3. Notably, the TQ strategy showed a statistically significant difference in precision compared to the other strategies in the mandible ($P < 0.001$). The experimental findings indicate that both Trios 3 and Trios 4 scanners were subjected to 10 repeated scans of the maxilla and mandible, resulting in a total of 120 scans. These scans were compared using file image overlap, and it was determined that each scanner requires its own optimized scanning strategy, particularly for full-mouth scanning of the maxilla and mandible and subsequent full-mouth reconstruction.

Similar arguments supporting our results were presented by Amornvit et al.,[24] who emphasized the importance of individualized sweeping strategies for each scanner, as even scans from the same series exhibited varying deviation values. In general, the scanning modes recommended by the manufacturer are deemed feasible for the Trios series. However, Trios 3 still exhibited significant deviation in the premolar/molar region of the maxilla, while the deviation values were generally smaller in the mandible due to directly visible operation. Conversely, in Trios 4, the areas with the highest deviation in both the maxilla and mandible were found in the transition area of posterior teeth, which aligns with the findings of Yehia et al.[28]

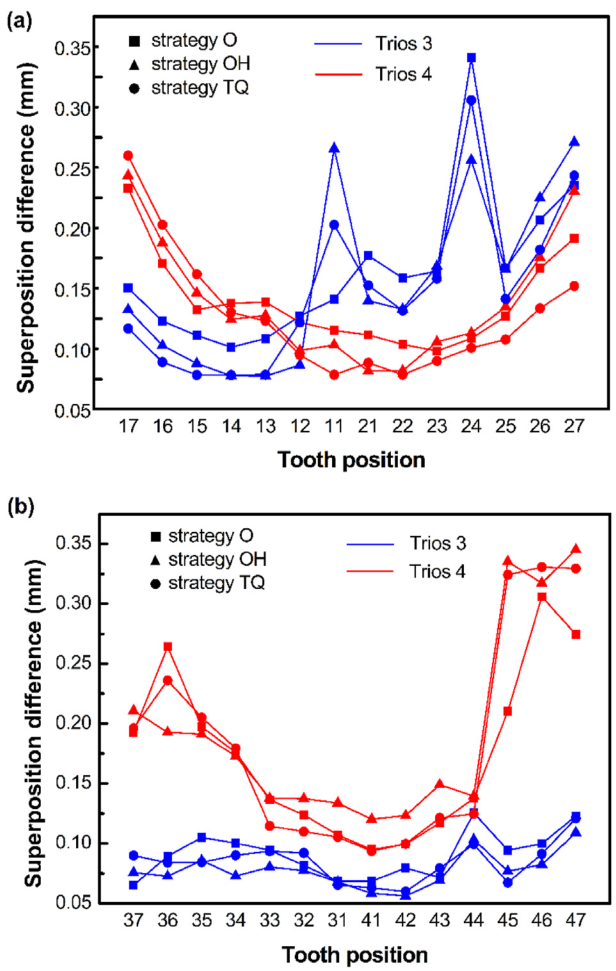

Figure 3 The mean deviation of each tooth position revealed significant difference from different scanning strategies and scanner. (a) Trios 4 differed greatly in the maxilla position in different tooth positions, and (b) Trios 4 did not perform better than Trios 3. Trios 3 performed better than Trios 4 at mandible ($P < 0.01$).

In the maxilla, the average trueness values for the three strategies ranged from 104 μm to 140 μm. Among these strategies, TQ exhibited the lowest trueness value, as shown in Table 1 and Fig. 3. While there is no clear consensus on the clinically acceptable deviation value for digital impressions in the literature, previous studies have reported a maximum clinically acceptable marginal gap of less than 120 μm; therefore, the Trios series, with its trueness values falling within this range, has the potential for widespread acceptance in clinical dentistry. Comparing the trueness in the maxilla, Trios 4 was found to be superior to Trios 3, which aligns with the findings of Róth et al.[27] However, when analyzing the deviation of each tooth, Trios 3 and Trios 4 exhibited different deviation patterns across different tooth areas, which could be valuable for clinical applications. Trios 3 showed higher deviation in the premolar and posterior areas, while Trios 4 exhibited higher deviation in the posterior area, regardless of the scanning strategy employed. These findings were consistent with those reported by Róth et al.[27] Moving on to the mandible, Trios 3 demonstrated low deviation among the three strategies, which is in line with the findings of Feng et al.[9] Additionally, Trios 4 exhibited higher deviation than Trios 3, particularly in the posterior area. This interesting observation may be attributed to the presence of the caries detection function in Trios 4, which could potentially impact image capture and model reconstruction, especially in the mandible.

In the maxilla, the three scanning strategies showed no statistically significant differences; however, the deviations gradually increased from the upper right to the upper left. Among the individual teeth, larger deviations were observed at teeth 11 and 24. The OH strategy exhibited the largest deviation at tooth 11, likely due to its position at a turning point, which could affect the scanning accuracy. Strategies O and TQ displayed larger deviations at tooth 24 compared to strategy OH. The TQ strategy was also influenced by the turning of the scanner, while the O strategy represented a common error often encountered in full-arch scanning. In the mandible, the OH strategy demonstrated the highest accuracy; however, unlike the maxilla, the differences in accuracy for individual teeth in the mandible did not show a gradual increase, and no significant variations occurred. This can be attributed to the fact that scanning the mandible requires less turning during hand motion, resulting in fewer or more minor errors.

Based on the results of this study, it is important for clinicians to take into account the choice of scanning strategy and the specific intraoral scanner when conducting digital impressions of the maxilla and mandible. In the case of the maxilla, both Trios 3 and Trios 4 demonstrated the ability to produce accurate digital impressions regardless of the scanning strategy employed. However, when focusing on the mandible, utilizing scanning strategy OH with Trios 3 or strategy TQ with Trios 4 might yield the lowest deviation and highest level of accuracy. Furthermore, clinicians should also consider the precision of the scanner during digital impressions, as a statistical difference in precision was observed in the mandible for both Trios 3 and Trios 4. Taking these factors into consideration could help ensure optimal results when using intraoral scanners in clinical cases.

It is crucial to acknowledge that this study had limitations regarding the specific range of scan sequences investigated, and additional research would be required to assess the accuracy and precision of these scanners in different clinical scenarios. Clinicians should exercise their professional judgment to determine the most suitable scanning strategy and scanner for each individual case. Additionally, it is worth noting that in this study, we observed that the differences in scanning accuracy between different strategies were more similar in the mandible compared to the maxilla, where greater differences were observed at turning positions. It is important to consider that direct comparisons with published results are challenging due to variations in study design, including different analysis methods, materials, and scanning techniques. Moreover, it is worth mentioning that this study did not consider the presence of tongue or saliva, which can potentially affect scanning quality. Further investigations are necessary to validate and corroborate these findings.

The choice of scanning strategy and intraoral scanner plays a significant role in determining the accuracy and

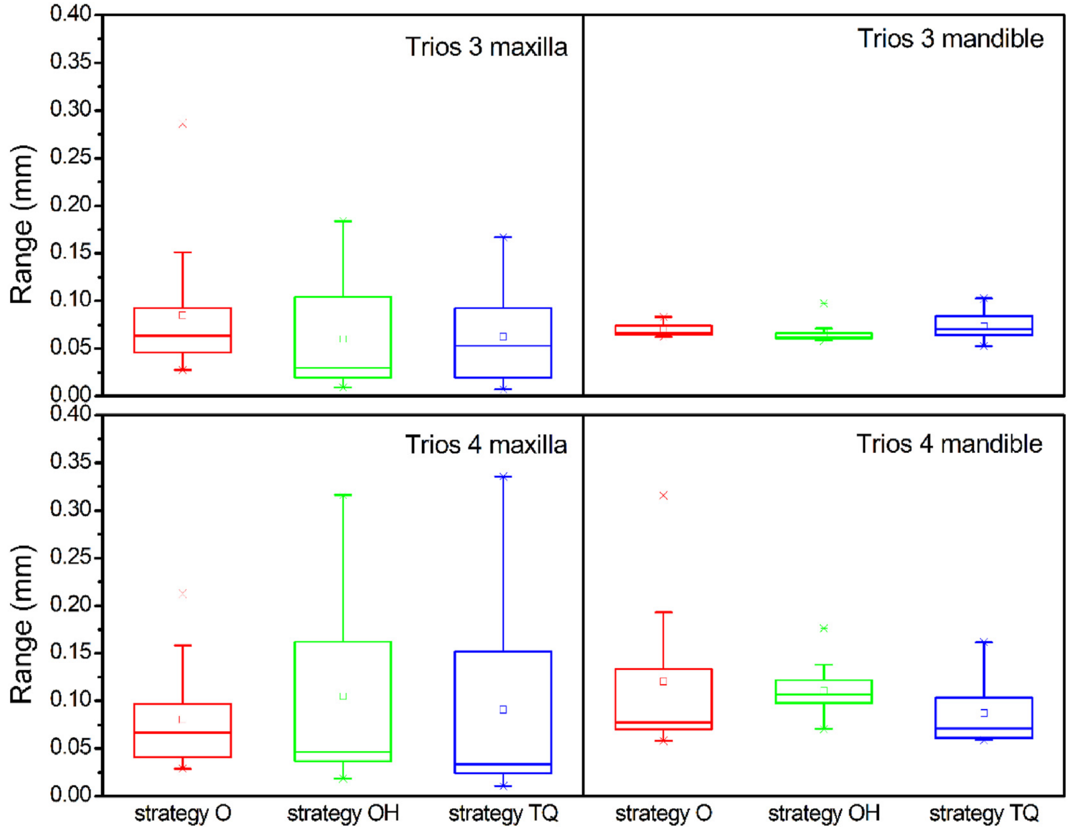

Figure 4 The boxplots comprehensively depict the precision differences in the corresponding scan sequential ranges.

Table 1 Maxilla mean absolute deviation of trueness in different strategies. (unit: mm).

	Strategy	Trios 3			Trios 4		
		Mean ± SD	95%CI	*P*-value	Mean ± SD	95%CI	*P*-value
Trueness	O	0.140 ± 0.120	(0.120, 0.160)	0.387	0.138 ± 0.110[a]	(0.120, 0.156)	0.006
	OH	0.131 ± 0.09	(0.116, 0.146)		0.115 ± 0.084[ab]	(0.101, 0.129)	
	TQ	0.123 ± 0.087	(0.109, 0.138)		0.104 ± 0.075[b]	(0.091, 0.127)	
Precision	O	0.085 ± 0.119[a]	(0.063, 0.106)	0.046	0.081 ± 0.088	(0.065, 0.096)	0.147
	OH	0.060 ± 0.069[b]	(0.048, 0.073)		0.105 ± 0.103	(0.087, 0.123)	
	TQ	0.062 ± 0.060[b]	(0.051, 0.073)		0.091 ± 0.103	(0.073, 0.109)	

*One-way ANOVA (three independent groups); *Multiple comparisons with *post hoc* Tukey test; different superscript letters in a column indicate statistical significance among groups ($P < 0.05$); strategy O (manufacturer's original method), strategy OH (segmental sequential ranges one half), and strategy TQ (segmental sequential ranges third quarter).

Table 2 Mandible mean absolute deviation of trueness in different strategies. (unit: mm).

	Strategy	Trios 3			Trios 4		
		Mean ± SD	95%CI	*P*-value	Mean ± SD	95%CI	*P*-value
Trueness	O	0.090 ± 0.032[a]	(0.085, 0.096)	0.008	0.174 ± 0.098	(0.158, 0.190)	0.281
	OH	0.078 ± 0.033[b]	(0.072, 0.083)		0.193 ± 0.103	(0.176, 0.210)	
	TQ	0.084 ± 0.038[ab]	(0.078, 0.091)		0.184 ± 0.100	(0.167, 0.200)	
Precision	O	0.028 ± 0.022	(0.024, 0.032)	0.073	0.085 ± 0.098[a]	(0.068, 0.102)	<0.001
	OH	0.024 ± 0.023	(0.021, 0.029)		0.074 ± 0.064[a]	(0.063, 0.085)	
	TQ	0.033 ± 0.034	(0.027, 0.039)		0.048 ± 0.046[b]	(0.040, 0.057)	

*One-way ANOVA (three independent groups); *Multiple comparisons with *post hoc* Tukey test; different superscript letters in a column indicate statistical significance among groups ($P < 0.05$); strategy O (manufacturer's original method), strategy OH (segmental sequential ranges one half), and strategy TQ (segmental sequential ranges third quarter).

precision of full-arch digital impressions in both the maxilla and mandible. In this study, strategy TQ demonstrated superior accuracy values for both Trios 3 and Trios 4, indicating its potential for achieving clinical application. Clinicians should take into account these results when making decisions about scanning strategies and intraoral scanners for specific cases, aiming to enhance the overall quality and reliability of digital impressions.

Declaration of competing interest

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

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