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Effect of Scanner Type and Scan Body Location on the Accuracy of Mandibular Complete-Arch Digital Implant Scans: An In Vitro Study

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Abstract

Purpose: To compare the accuracy (trueness and precision) of scans of a newly introduced intraoral scanner (IOS) (Virtuo Vivo) and a widely used IOS (Trios 3) to a laboratory scanner (LBS) (Cares 7 SERIES) for 6 implants placed in an edentulous mandible, and to investigate the effect of scan body location on trueness.
Material and methods: Scanbodies were tightened on 6 implants placed in an edentulous polymethylmethacrylate mandibular model. An industrial scanner was utilized to generate a master reference model STL file. Three different scanners were used to scan the model (2 IOSs and 1 LBS), and the scans (n = 10) were exported into STL files. Best-fitting algorithm was used to superimpose test scans over the MRM-STL (nominal). ANOVA and Tukey HSD tests were performed to analyze the data ($\alpha = 0.05$).
Results: The distance deviations in Car7-LBS scans were the highest ($p < 0.001$), whereas those in Tri-IOS scans were the lowest ($p < 0.001$). Vir-IOS had lower angular deviations than those of Tri-IOS ($p = 0.031$). In Vir-IOS scans, SB5 had higher distance deviations than SB2 ($p = 0.029$) and SB3 ($p = 0.044$). In Car7-LBS scans, SB1 had higher distance deviations than SB3 ($p = 0.015$) and SB5 ($p = 0.005$). In Tri-IOS scans, SB1 had higher mean distance deviations than SB2 and SB5 ($p = 0.005$). Vir-IOS had lower precision than Car7-LBS (distance deviation data) ($p = 0.01$). No difference was found among scanners for the precision of angular deviation data ($p = 0.840$).
Conclusion: When trueness and precision were considered, distance and angular deviations depended on the scanner type. None of the scanners outperformed others in accuracy considering all distance and angular deviations. Scan body location affected only the trueness (distance deviations).

An accurate transfer of three-dimensional (3D) implant position is a crucial step to fabricate accurately fitting implant supported prosthesis and to prevent biomechanical complications.[1,2] With the launch of different intraoral (IOS) and laboratory (LBS) scanners and ongoing innovations in computer-aided design and computer-aided manufacturing (CAD/CAM) technology, digital scans of single and multiple implants have been reported to be as accurate as conventional impressions.[3–8]

Scanning implants in completely edentulous arches is a challenging situation for scanners.[4,5,9,10] The limited number of reference points may lead to errors because proper stitching of images and mathematical interpretion becomes challenging.[2,5,11] Recapturing the missing areas is also difficult and may lead to errors because soft tissues with reflection may be captured in different positions.[12] Scanning the mandible is particularly challenging because scans may be affected from the movement of the tongue and the mucosa changes during mandibular movements.[10,12,13] Also, the similarity in the scan body (SB) morphology when multiple implants are scanned results in difficulties in their 3D individualization by the scanner.[2,4]

The quality of digital scans depends on accuracy and resolution of the scanner.[3,5,7] Accuracy is the trueness combined with precision.[7] Trueness is the closeness of agreement between the arithmetic mean of a number of test results and a reference value.[14] Precision is the closeness of agreement between test results, which is the repeatability of measurements.[14] A scanner needs to have high precision and trueness to achieve closeness of repeated scans and to more closely replicate the actual dimensions of the originally scanned object.[11,14–16] There are conflicting results for the accuracy of different scanners.[3,5,7,8]

Information on the acceptability of accuracy of scanners for clinical implementation of scans of complete-arches is sparse. Differences in accuracy have been reported for different scanner technologies.[3,4,5,7] Therefore, accuracy assessment of recently launched and currently available scanners with different technologies is a prerequisite for their clinical application.[3,9]

To the authors' knowledge, the accuracy of Virtuo Vivo in the edentulous mandible in a multiple implant scenario hasn't been evaluated. Its comparison with a commonly used scanner with a different mechanism can be clinically beneficial.[3] The purpose of the present study was to compare the accuracy (trueness and precision) of 2 different IOSs (Virtuo Vivo and Trios 3) and an LBS (Cares 7 SERIES, 7S-LBS) in an edentulous mandible with 6 implants, and to investigate the effect of scan body location on the scan trueness. The first null hypothesis was that the scan accuracy (trueness and precision) would not be different when different scanners were used. The second null hypothesis was that the trueness would not change depending on the scan body location.

Materials and methods

A polymethylmethacrylate (PMMA) edentulous mandibular model including 6 implants (4.1 mm, Tissue Level Regular Neck Standard Plus; Straumann, Basel, Switzerland) was used. The implants were placed at canine, second premolar, and second molar positions using a surgical guide (Pro Arch Guide; Straumann, Basel, Switzerland). The platform of the implants was 1 mm below the surface of the model. The approximate distances were 15 mm between implants at canine positions, 4 mm between implants at canine and second premolar positions, and 5 mm between implants at second premolar and molar positions. Scanbodies (CARES RN Mono; Straumann, Basel, Switzerland) were tightened by one operator onto each implant as recommended by the manufacturer.[17]

A powder (Vita powder scan spray; Vita Zahnfabrik, Bad Säckingen, Germany) was sprayed on the model's surface, and the model was scanned 3 times with an industrial, metrology-grade scanner (ATOS Core 80 5MP; GOM GmbH, Braunschweig, Germany), reverse engineered, and digitized with software (Pro 8.1; GOM GmbH, Braunschweig, Germany) to create a master reference model standard tessellation language (MRM-STL) file.[3] The industrial-grade scanner has 6 μm sphere space and 8 μm size errors.[3,18] Then, 3 different scanners (Table 1) including 2 different IOSs (Vir-IOS and

Table 1 Tested scanners and reference scanner

Scanner	Manufacturer	Scanner type and scan mechanism	Manufacturer's reported accuracy
Virtuo Vivo (Vir-IOS)	Dentalwings, Montreal, Quebec, Canada	A blue laser intraoral scanner;Technology: multiscan imaging	No reported value
TRIOS 3 (Tri-IOS)	3Shape, Copenhagen, Denmark	A structured light intraoral scanner; Technology: confocal microscopy and ultrafast optical scanning	6.9 ±0.9 μm trueness and 4.5 ±0.9 μm precision
Cares 7 SERIES Dental Wings (Car7-LBS)	Dentalwings, Montreal, Quebec, Canada	Laboratory scanner; Technology: Blue Laser Illumination	15 microns
ATOS Core 80 5MP	GOM GmbH, Braunschweig, Germany	Industrial-grade scanner; Triple scan principe, blue light technology	6 μm sphere space and 8 μm size errors

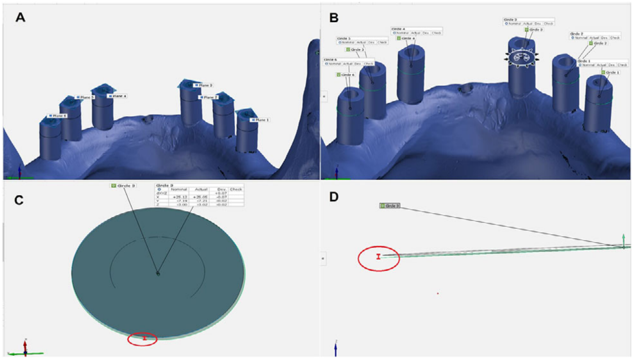

Figure 1 Trueness of scans. A, Flat planes created on the top surfaces of the scan bodies (one in nominal, one in test scan); B, Two circles were generated in scan bodies 3 mm apical and parallel to these flat planes; C, For distance deviations, the linear deviations of these 2 circles were calculated in x, y, and z directions; D, For angular deviations, the angle between these 2 circles was calculated.

Tri-IOS) and an LBS (Car7-LBS) were utilized to scan the master model. A power analysis was done for 10 test scans of each scanner and 83% power was found; the required effect size f to find statistical significance was 0.76. Therefore 10 test scans were made for each scanner. When IOSs were used, all scans were initiated on the left side of the model. Vir-IOS has no recommended scan strategy by its manufacturer.[19] Thus, all scans were made by using a scan protocol recommended by the manufacturer of Tri-IOS[20] to standardize the scans of both IOSs. The occlusal surfaces were scanned first, followed by the lingual and the buccal surfaces. When LBS was used, scans were also performed according to the manufacturer's recommendation.[21] Scanners were calibrated before scans, and the master model was then scanned consecutively 10 times (n = 10) with each scanner. Temperature and humidity were regulated, and all scans were performed in the standardized laboratory condition by the same operator (G.Ç). A scan was accepted as complete when there was no major hole in the scan of the master model and all scan body surfaces were acquired.[3,11]

All test scans obtained with IOSs and LBS were exported into STL files. The best-fit algorithm was used to superimpose test scan STLs over the MRM-STL (nominal) (GOM Inspect 2019; GOM GmbH, Braunschweig, Germany).[3] For the first alignment, the prealignment function of the software was used to superimpose the models (nominal to IOS and LBS scans).[3] For further superimposition of the models, "Local best-fit" function of the software was used.[3] To avoid any superimposition errors, scan bodies were not utilized as the reference areas.[3] Superimposition was done using the unaltered specific reference areas on the models; lingual of the surgical guide insertion osteotomy hole located at midline as the anterior reference and notches on alveolar ridges distal to the most posterior scan bodies as posterior references.

For trueness of scans, the distance and angular deviations between the scan bodies in the test scan (IOSs or LBS) and the nominal scan (MRM-STL) (Fig 1) were measured. For each scanner, the mean distance and angular deviations at all scan body locations were calculated in scans.[3,11] A total of 180 measurements were performed to compare deviations. On a coordinate system,[3,11] a flat plane was created on the top surfaces of the scan bodies (nominal and test scans) (Fig 1A). Two circles were generated on scan bodies 3 mm apical and parallel to the flat planes (Fig 1B), as scan bodies used in this study have a flat surface that is approximately 3 mm in height from the top surface.[3] Then, linear deviations between these 2 circles were calculated in x, y, and z directions (Fig 1C).[3] The distance deviations were calculated for every scan body location and scanner.[6]

For angular deviations, the nominal element was accepted as 0-out one position and the angle between previously created circles (1 in test and 1 in nominal scan) was calculated (Fig 1D). The value of the angle was recorded for all scan bodies.[3]

Scan bodies were numbered and labeled 1 through 6 (SB1: mandibular left second molar, SB2: mandibular left second premolar, SB3: mandibular left canine, SB4: mandibular right canine, SB5: mandibular right second premolar, SB6: mandibular right second molar) to assess the effect of scan body location.

For precision, the degree of variance among groups of test scans was calculated. Means and 95% confidence limits for distance and angular deviations were calculated for all scanner-scan body location combinations (IBM SPSS Statics 25.0; SPSS Inc, Chicago, IL). A repeated measures 2-way analysis of variance (ANOVA) was done and the main effects were the scanner type and the scan body location (trueness). For precision, the homogeneity of the variances among scanners was analyzed.[3,11] A Tukey HSD test was used to resolve any significant interaction. Further comparisons were made with a student's t-test ($\alpha = .05$).

Results

The scanner type and the scan body location interaction were found significant for distance deviation (trueness) ($p = 0.009$, F ratio: 2.465) and for angular deviation (trueness) ($p = .0024$, F ratio: 2.15). In terms of trueness, Car7-LBS scans had the highest ($p < 0.001$) and Tri-IOS scans had the lowest mean distance deviations ($p < 0.001$) (Table 2, Fig 2). Tri-IOS scans had higher angular deviations than those of Vir-IOS ($p = 0.031$) (Table 2, Fig 3).

According to the Tukey HSD test, for Vir-IOS, SB2 ($p = 0.029$) and SB3 ($p = 0.044$) had lower mean distance deviations than SB5. For Car7-LBS, SB3 ($p = 0.015$) and SB5 ($p = 0.005$) had lower mean distance deviations than SB1. For Tri-IOS, SB2 and SB5 ($p = 0.005$) had lower mean distance deviations than SB1 (Table 3). For all scanners (Vir-IOS; $p \geq 0.414$, Car7-LBS; $p \geq 0.316$, Tri-IOS; $p \geq 0.078$), no significant effect of location was found on angular deviations ($p = 0.759$, F ratio: 0.522) (Table 3).

For precision, differences were found in distance deviations ($p = 0.013$, F-ratio :5.14) between scanners. Only Vir-IOS and Car7-LBS had a difference and Vir-IOS had lower precision for distance deviation values ($p = 0.01$) (Table 2). No difference was found among scanner types for angular deviation ($p = 0.840$, F-ratio: 0.18) (Table 2).

Table 2 Mean distance (μm) and angular deviations (°) for tested scanners (n = 10) with regards to trueness and precision

Trueness/precision	Scanner	Mean± SD	Pairs	*p*
3D Distance Deviation (μm) for Trueness	Vir-IOS	62.74 ± 42.02^B^	Vir-IOS∗Car7-LBS	<0.001
			Vir-IOS∗Tri-IOS	<0.001
	Car7-LBS	87.41 ± 25.2^C^	Car7-LBS∗Vir-IOS	<0.001
			Car7-LBS∗Tri-IOS	<0.001
	Tri-IOS	39.88 ± 18.71^A^	Tri-IOS∗Vir-IOS	<0.001
			Tri-IOS∗Car7-LBS	<0.001
Angular Deviation (°) for Trueness	Vir-IOS	0.18 ± 0.11^D^	Vir-IOS∗Car7-LBS	=0.468
			Vir-IOS∗Tri-IOS	=0.031
	Car7-LBS	0.20 ± 0.12^DE^	Car7-LBS∗Vir-IOS	=0.468
			Car7-LBS∗Tri-IOS	=0.356
	Tri-IOS	0.23 ± 0.12^E^	Tri-IOS∗Vir-IOS	=0.031
			Tri-IOS∗Car7-LBS	=0.356
3D Distance Deviation (μm) for Precision	Vir-IOS	14.75 ± 7.9^G^	Vir-IOS∗Car7-LBS	=0.01
			Vir-IOS∗Tri-IOS	=0.14
	Car7-LBS	5.71 ± 5.5^F^	Car7-LBS∗Vir-IOS	=0.01
			Car7-LBS∗Tri-IOS	=0.462
	Tri-IOS	9.13 ± 5.45^FG^	Tri-IOS∗Vir-IOS	=0.14
			Tri-IOS∗Car7-LBS	=0.462
Angular Deviation (°) for Precision	Vir-IOS	0.05 ± 0.04^H^	Vir-IOS∗Car7-LBS	=0.839
			Vir-IOS∗Tri-IOS	=0.901
	Car7-LBS	0.06 ± 0.04^H^	Car7-LBS∗Vir-IOS	=0.839
			Car7-LBS∗Tri-IOS	= 0.990
	Tri-IOS	0.06 ± 0.05^H^	Tri-IOS∗Vir-IOS	=0.901
			Tri-IOS∗Car7-LBS	=0.990

Different uppercase letters indicate significant differences (adjusted $p < 0.001$). SD, Standard deviation.

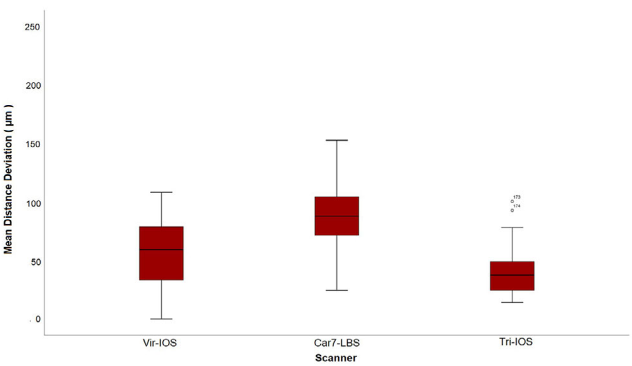

Figure 2 Boxplots for distribution of distance deviation (trueness) data including minimal, median, and maximum for tested scanners.

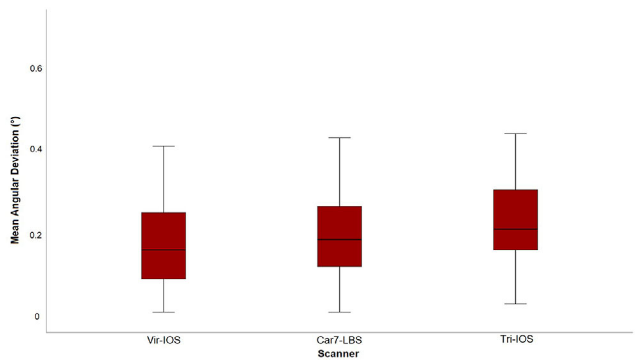

Figure 3 Boxplots for distribution of angular deviation (trueness) data including minimal, median, and maximum for tested scanners.

Discussion

The scanner type significantly affected the trueness. For precision, the scanner type significantly affected the distance deviation. Thus, the first null hypothesis was rejected. Scan body location significantly affected the trueness (distance deviations). Therefore, the second null hypothesis was also rejected.

Because scanner technology was reported to affect accuracy,[3,5,22] scanners with different technologies were tested in the present study (Table 1). Virtuo Vivo is a newly introduced IOS and there are limited studies on its complete-arch implant scan accuracy.[3] However, Trios 3 IOS's accuracy has been reported[1,2,11,22] and the comparison of a new IOS with a widely used IOS was considered. An LBS was also evaluated because there are conflicting results on whether IOSs or LBSs are more accurate.[3]

For distance deviations for trueness, significant differences were found among all scanners, as shown in previous studies.[3,5,7,8,15,22,23] Tri-IOS had the lowest, whereas, Car7-LBS had the highest distance deviation for trueness. Similarly, it was previously[8] reported that different IOSs (CEREC Omnicam and True Definition) had different 3D deviations in edentulous mandible with 5 implants. Mangano et al[23] reported

Table 3 Mean distance (μm) and angular deviations (°) (trueness) with scanners at different scan body locations

	Scan body location	Vir-IOS	Car7-LBS	Tri-IOS
Mean distance deviation ±SD	SB1	77.16 ± 78.36**AB**	111.6 ± 15.45**C**	57.6 ± 21.43**E**
	SB2	33.9 ± 29.47**A**	82.2 ± 21.72**CD**	29.41 ± 15.1**F**
	SB3	36.55 ± 15.08**A**	77.11 ± 32.04**D**	43.17 ± 18.2**EF**
	SB4	68.72 ± 22.04**AB**	86.31 ± 20.58**CD**	43.1 ± 19.24**EF**
	SB5	88.07 ± 27.76**B**	73.2 ± 17.07**D**	29.6 ± 10.8**F**
	SB6	72.03 ± 17.68**AB**	94.05 ± 25.25**CD**	36.45 ± 13**EF**
Mean angular deviation ±SD	SB1	0.14 ± 0.06**G**	0.18 ± 0.12**H**	0.31 ± 0.13**J**
	SB2	0.14 ± 0.09**G**	0.15 ± 0.12**H**	0.27 ± 0.14**J**
	SB3	0.15 ± 0.07**G**	0.21 ± 0.1**H**	0.24 ± 0.11**J**
	SB4	0.23 ± 0.15**G**	0.24 ± 0.14**H**	0.17 ± 0.09**J**
	SB5	0.23 ± 0.13**G**	0.19 ± 0.16**H**	0.18 ± 0.07**J**
	SB6	0.19 ± 0.13**G**	0.26 ± 0.09**H**	0.24 ± 0.10**J**

Different uppercase letters indicate significant differences for different scan body (SB) locations in the same scanner (adjusted $p < 0.001$). SD, standard deviation.

trueness values slightly lower than those in the present study for the scans of an edentulous maxilla with 6 implant analogues. The difference in reported trueness may be because of the scanner's version and software. In previous studies,[7,10,24] the mean distance deviation ranged between 47 and 226 μm for complete-arch implant scans. Tri-IOS had a mean distance deviation below this range. Similarly, Vandeweghe et al[4] (28 μm trueness) found Trios IOS more accurate than other IOSs in edentulous mandible with 6 implants. Papaspyridakos et al[6] reported slightly higher trueness with Trios 3 compared with its trueness in the present study. Although differences were found among tested scanners, the distance deviation results for all scanners were lower than clinically maximum acceptable misfit level (91-111 μm) reported.[24]

For angular deviation for trueness, Vir-IOS had lower angular deviations than Tri-IOS, and no significant differences were found when compared with Car7-LBS. Mizumoto et al[11] reported angular (0.41-0.52°) and distance deviations higher than the scanners tested in the present study, where they scanned an edentulous maxilla with 4 implants by using Trios 3. Difference in results may be due to the difference in number of implants and scan body designs, and the study design which included different operators.

For precision, Vir-IOS had higher distance deviations than the Car7-LBS. Similarly, significant differences were found in distance deviation of precision among different scanners in a previous study.[5] Contrarily, Imburgia et al[7] reported no significant difference for the precision among different IOSs however, the authors reported that Trios 3 had the best precision in a fully edentulous model, which was lower than the precision of the same scanner in the present study. Difference in precision may be because of the difference in designs for scan bodies in different implants. The authors[7] have used bone level implants with scan bodies in a different design than the ones used in the present study. Mizumoto et al[2] have evaluated the effects of 5 different scan bodies in different designs and found that the scan body design affected the accuracy of complete-arch digital implant scans. In addition, the effect of operator and/or operator experience on implant scan accuracy has been studied and; operator's effect has been shown to be significant on the accuracy of digital implant scans.[25] The difference in results may be due to the effect of the operator/operator experience. The findings of the present study should be further elaborated with studies involving different scan body designs and operators with different levels of experience or increased number of operators with similar experience.

A previous study tested scanners identical to the ones tested in this study,[3] and reported differences in accuracy. Contrary to present study results, Vir-IOS had the lowest and Car7-LBS had the highest trueness (distance deviations).[3] Contrarily, Vir-IOS had significantly lower angular deviations (trueness) than Car7-LBS.[3] In line with the present study, Vir-IOS had lower precision (distance deviation) than Car7-LBS, but contrarily, also lower precision than Tri-IOS.[3] Again, in contrast, Car7-LBS had lower precision (angular deviation) than Tri-IOS.[3] It should be noted that an edentulous maxilla with 4 bone level implants was scanned in the previous study,[3] and the scan bodies were attached to multiunit abutments (0-degree for anterior and 17-degree for tilted posterior implants). However, in the present study, 6 tissue level implants and implant-level scan bodies were used in an edentulous mandible. Therefore, differences in results may be due to the differences in implant type (bone vs tissue level), implant vs abutment level scan bodies, the number of implants, and the distances between each other. In other previous studies,[25,26] digital implant impression accuracy was also influenced by the implants being bone- vs tissue-level.

In the present study, distance deviation (trueness) was affected from the scan body location; however, conflicting results were found among different scanners. Although the scan patterns were same and started from the same side, distance deviations were not similar between IOSs. With Tri-IOS, the first scanned scan body (SB1) had significantly higher distance deviations than the second (SB2) and the fifth (SB5) scanned. Whereas, in Vir-IOS, the fifth scanned (SB5) had significantly higher distance deviations than the second (SB2) and the third (SB3). Previous studies reported that IOSs had difficulty in differentiating intraoral scan bodies in same shape and defining their location in the arch when scanning multiple implants.[4,10,27,28] Therefore, difference in scanbody location's effect may be due to different scanning technologies.[3,19,20] Similarly, Mizumoto et al[11] reported that implant location affected the distance deviation. The scan body location may be expected to less affect distance deviation when LBS is used because scanning is performed with the robotic movement of the table.[21] However, differences were found in distance deviation among some scan body location pairs with LBS. This may be due to the scanning technology of the scanner and how it interacts with the scanbody shape.

The angular errors are possible with an increase in the length of the scanned arch because registration errors may accumulate while patching 3D surfaces.[13,16] However, in the present study, no significant difference was found in angular deviation (trueness) at different scan body locations in any of the scanner. Similarly, in a previous study,[3] scan body location influenced the distance deviations and had no significant effect on angular deviations (trueness).

In previous studies, conflicting results were reported for different scan body locations.[9,11] Gimenez et al[9] reported that ZFX Intrascan scanner had improved accuracy in the last scanned quadrant, whereas 3D Progress IOS had improved accuracy in the first scanned quadrant in the edentulous maxilla with 6 implants. Mizumoto et al[11] found that the scan body, which was scanned first had higher deviations than the others. The most distal implant was reported to be the reason for inaccuracy in some previous studies,[4,6] however, the most distal implant did not have higher deviations in the present study. The results of present study do not lead to clear conclusions on the effect of the side scans started and the location of the implants on deviations.

The scanned arch may have an effect on the accuracy of scans as maxilla and mandible differ in surface topography (rugae vs no rugae), surface area, amount of movable mucosa, presence of the tongue in the mandible, presence of mandibular movements vs the fixed maxilla.[29–31] The absence of topographical advantages like rugae in the mandible adds challenge when scanning. [29–31] In addition, one of the patient-specific factors is the mandibular deformation during jaw opening.[29] During scans, the largest jaw opening occurs when the posterior teeth or implants are scanned[29] that might affect scanning and accuracy. Therefore, the intraoral scans of mandibular complete-arch multiple-implant situations can be challenging[29–31] and the number of studies on their accuracy is limited.[4,8,10] To verify the effect of tongue, amount of movable mucosa, the presence or absence of keratinized tissue, mandibular movements, and mouth opening on the complete-arch implant scan accuracy, and to further conclude whether maxillary or mandibular scans are more accurate, future clinical studies should be considered to investigate the effect of these factors on the scan accuracy. When the clinically acceptable misfit of 91 to 111 μm and small distance deviations relative to previous studies are considered,[7,10,24] all tested scanners showed promising scan accuracy. To recommend the tested scanners for the scans of edentulous mandible with 6 implants and corroborate the present study results, future clinical studies which include patient-specific factors are required and resulting framework fit should also be evaluated. Tested scanners enabled scans of adjacent implants with identical scan bodies because there was no significant difference among all scan body pairs. The selection criteria for an IOS for clinicians depend on many factors including, high accuracy, powder requirement, open or closed system for STL transfer, cost-benefit ratio, scanner head size, and time-effectiveness.[1,32,33] Purchasing and managing costs are also important for clinicians.[33] The more affordable scanner's (Virtuo Vivo) accuracy was similar to that of a commonly used scanner (Trios 3) in one of the most challenging situations possible. Accordingly, although the cost of an IOS is not the only criteria, the present study results are promising for clinicians searching for an affordable and accurate scanner.

The scan strategy was previously reported to affect the accuracy.[34] Different accuracy may be obtained with varying scan strategies for Vir-IOS and future studies should focus on the scan strategy's effect. Nevertheless, the used scan strategy may be a good alternative, when favorable accuracy results are considered. The alignment of reference and test scans is an important step that needs to be carefully performed in a standardized manner to prevent stitching errors. A commonly used metrology software was used to align the scans by one experienced operator. All alignment and processing steps were standardized throughout the experiments.

LBSs are commonly used to scan models fabricated from conventional impressions, which are prone to errors.[6,8] Results of LBS in the present study may be different if the LBS scans were done following conventional impression steps, which needs to be further evaluated. In addition, different results can be obtained with laboratory scanners which have higher accuracy than tested laboratory scanner. Future studies should also compare different laboratory scanners. In the present study, the applied spray powder was not cleaned from the surface for standardization and to prevent any damage to scan body surfaces. However, spray is not required for all current intraoral and laboratory scanners. Although a very thin layer of spray was applied in the present study, the presence of powder can be considered as a limitation and further evaluation of the effect of powder layer on the accuracy should be performed. With the improvements in CAD/CAM technology, manufacturers introduce new scanners or software upgrades.[35] Scanner technology and hardware and software components of the scanner were reported to affect the accuracy.[3,35] Therefore, in future studies, comparison of newly introduced IOSs or software updates of tested scanners would be of interest. Scan path, calibration, operator(s), number of implants and their distance, implant angulation and depth, the scanned arch (maxilla or mandible) are also potential sources that may affect the accuracy,[34,35] and should be further evaluated. Presence of saliva, blood, tongue, and patient-related issues may complicate the quality of a digital scan.[7,15] Further clinical verification of the present study results with in vivo studies is necessary.

Conclusion

For trueness, the laboratory scanner had higher distance deviations than the intraoral scanners; however, for precision, the laboratory scanner had lower distance deviation than the Virtuo Vivo intraoral scanner. The Virtuo Vivo intraoral scanner had higher distance deviations (lower trueness) than the Trios 3 intraoral scanner, but their precision was similar. For angular deviations, the trueness of intraoral scanners was different. However, the precision of scanners was similar. When trueness and precision were considered, distance and angular deviations depended on the scanner type. None of the scanners outperformed others in accuracy considering all distance and angular deviations. Scan body location affected only the trueness (distance deviation).

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Conflict of Interest

The authors declare no conflict of interest. The authors do not have any financial interest in the companies whose materials are included in this article.

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