THE JOURNAL OF PROSTHETIC DENTISTRY

CLINICAL RESEARCH

Impact of intraoral scanner, scanning strategy, and scanned arch on the scan accuracy of edentulous arches: An in vitro study

Faris Z. Jamjoom, BDS, MS, DMSc, FRCDC,[a] Adhwaa Aldghim,[b] Omar Aldibasi, MPH, PhD,[c] and Burak Yilmaz, DDS PhD[d]

ABSTRACT

Statement of problem. The scanning strategy used when making complete arch digital scans affects the accuracy of the scan, and the accuracy of the strategy may be influenced by the scanner used. However, these effects have not been investigated thoroughly with complete arch edentulous scanning.

Purpose. The purpose of this in vitro study was to determine the effect of scanning strategies and the scanned arch on the accuracy of complete arch edentulous scans using 2 intraoral scanner (IOS) systems.

Material and methods. Two IOSs were used (TRIOS 4 and Emerald S) to scan maxillary and mandibular typodonts using 6 scanning strategies (test scans), and conventional impressions of both arches were also made. By using a metrology software program, test scans were superimposed onto a reference scan, and the root mean square (RMS) of the absolute deviation values was calculated to express trueness. The sample with the best trueness was used as reference onto which the remaining samples from the same group were superimposed, and the RMS of the absolute deviation values was calculated to express precision. Statistical modeling was applied using the fixed effects models (α=.05).

Results. The main effects of scanner and strategy significantly impacted the trueness RMS values (P<.001), with significant interactions between them (P=.012). The main effects of scanner, strategy, and arch significantly impacted the precision of RMS values (P=.004), (P=.033), and (P=.023). Conventional impressions and the TRIOS 4 scanner had comparable accuracy, while the Emerald S scanner was inferior to both. P-O-B had the highest overall accuracy and strategy ZZ had the worst. Better precision was found with the maxillary arch.

Conclusions. The scanner type and scanning strategy significantly impacted the accuracy of the digital scans of completely edentulous arches, with a significant interaction between scanner and strategy. The arch being scanned had a significant effect on scan precision but not on scan trueness. (J Prosthet Dent 2023;■:■-■)

Computer-aided design and computer-aided manufacturing (CAD-CAM) systems and digital technologies continue to streamline the dental workflow and have become popular for providing complete dentures.[1,2] CAD-CAM fabricated dentures can be provided in fewer appointments and can simplify the clinical and laboratory steps involved in fabrication.[2,3] Current CAD-CAM denture protocols include the digitization of a stone cast or a conventional impression with a laboratory scanner.[2,4,5] However, this protocol does not eliminate the errors related to the dimensional changes of the impression material or the dental stone or the discomfort and gagging associated with the conventional impression procedure,

Funding: Supported by the King Abdullah International Medical Research Center (KAIMRC) [NRC22R/156/03].
[a]Assistant Professor, Restorative and Prosthetic Dental Science Department, College of Dentistry, King Saud Bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia; King Abdullah International Medical Research Center (KAIMRC), Riyadh, Saudi Arabia.
[b]Dental Student, College of Dentistry, King Saud Bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia; King Abdullah International Medical Research Center (KAIMRC), Riyadh, Saudi Arabia.
[c]Biostatistician, Department of Biostatistics and Bioinformatics, King Abdullah International Medical Research Center (KAIMRC), Riyadh, Saudi Arabia; King Saud Bin Abdulaziz University for Health Sciences, Riyadh, Saudi Arabia.
[d]Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; Associate Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University, Columbus, Ohio.

Clinical Implications

Digital intraoral scans of completely edentulous arches have been established as a suitable alternative to conventional methods with comparable accuracy levels. However, a complete understanding of the variables that impact the digital scans of completely edentulous arches is still lacking. The scanning strategy used was found to affect the trueness and precision of the digital scans of completely edentulous arches depending on the type of scanner. The arch being scanned also affects the precision of the digital scans of completely edentulous arches.

and storage space for the impressions and casts is still required.[5-8] Using intraoral scanners (IOSs) for the fabrication of complete dentures has the potential to overcome the errors associated with conventional impression making and may also simplify and standardize the fabrication process.[4,9] Furthermore, digital scans can capture the intraoral tissues under true mucostatic conditions.[3,6,9]

Digital scans have not yet been recommended for routine use with edentulous arches.[10-12] Clinical and in vitro studies have investigated the feasibility of digital scans of completely edentulous arches using IOSs.[4,6,10-17] Although accuracy levels have been reported to be comparable with conventional impressions, considerable variability has been reported.[4,6,10,11,13-17] The lack of anatomic variation and reference points in the edentulous arch can introduce errors in the image-stitching process,[5,10,18-20] particularly with large smooth areas such as the palate.[13,18,21,22] In addition, dynamic and movable tissues are difficult to capture correctly, producing errors in denture extensions.[5,11,18,23] Nevertheless, the use of IOSs for the fabrication of complete dentures has been reported and can be a suitable alternative to conventional methods.[3,9,23-27]

Measuring the accuracy of digital scans according to the International Organization for Standardization (ISO) standard 5725-1 includes the evaluation of both trueness and precision.[28] Trueness describes how close the tested samples agree with an accepted reference, whereas precision describes how close repeated measures of a sample agree with one another.[28] The accuracy of digital scanning in general is affected by the IOS system, light source, scanning field, operator experience, and scanning strategy.[12,18,20,29,30] Different IOS manufacturers have proposed different scanning strategies based on the technology used.[29,31,32] Scanning strategy refers to the specific path followed by the IOS head along the scanned object.[33] While the true impact of scanning strategy has not been completely understood, variations in accuracy have been reported, depending on the scanning strategy used.[18,29,31-35] Furthermore, the effect of scanning strategy on the accuracy of digital scans has been reported to differ depending on the IOS used.[31,32,34,35]

Most IOS manufacturers recommend a specific scanning strategy for their system, but the strategy is usually described for dentate arches.[36,37] Different scanning strategies and techniques for scanning edentulous arches have been described,[3,7,14,17-19,21,24,38] but accuracy analyses are lacking. Zarone et al[18] investigated the influence of different scanning strategies on the accuracy of intraoral scans in vitro and concluded that scanning strategy had a significant impact on the accuracy of scans, particularly, when anatomic landmarks were well-defined. The authors are unaware of another study that investigated scanning strategies for complete arch edentulous digital scans. Therefore, the purpose of this study was to determine the impact of different scanning strategies and the scanned arch on the accuracy of complete arch edentulous scans when 2 IOS systems are used and to compare the results with conventional impression techniques. The null hypotheses were that, for each IOS, scanning strategy and the scanned arch would have no impact on the accuracy of complete arch edentulous scans and that no difference would be found between the accuracy of digital scans when using IOSs and conventional impressions.

MATERIAL AND METHODS

A pair of maxillary and mandibular completely edentulous typodonts with artificial mucosa (EDE1001-UL-UP-M; Nissin Dental Products Inc) were used. The maxillary and mandibular typodonts were scanned with an ISO 12836 compliant dental laboratory scanner (E4; 3Shape A/S) with an accuracy of 4 μm. The digital scans were saved in standard tessellation language (STL) format and used as the reference scans for all comparisons.

Ten conventional impressions of the maxillary and mandibular arches of the typodont were made at room temperature with polyvinyl siloxane (PVS) impression material in a custom tray as described by Chaffee et al [39] Briefly, the peripheral border of the typodont was impressed using heavy-body material (Any-Flex Heavy; MEDICLUS Co, Ltd) in a custom tray. A wash was made with a light-body material (Any-Flex Light; MEDICLUS Co, Ltd). The impressions were digitized with the same laboratory scanner. Two intraoral scanners with different scanning mechanisms were used (TRIOS 4; 3Shape A/S) (Emerald S; Planmeca OY). Scans of the maxillary and mandibular typodonts were made and repeated 10 times using 6 scanning strategies for a total of 240 recordings.

The scanning strategies were based on those recommended by the scanner manufacturers, were used as in previous studies, or were variations devised by the authors.[3,7,14,17-19,24,25,36,37] The 6 strategies included in this study were labeled according to the order of surfaces scanned and were as follows (Fig. 1A-F): B-O-P: Starting posteriorly and proceeding along the buccal aspect of the ridge to the other side, returning along the occlusal aspect, and finally scanning the palatal or lingual aspect. P-O-B: Starting posteriorly and proceeding along the palatal or lingual aspect of the ridge, returning along the occlusal aspect, and finally scanning the buccal aspect. O-B-P[3,17-19,24,36,37]: Starting posteriorly and proceeding along the occlusal aspect of the ridge to the other side, returning along the buccal aspect, and finally scanning the palatal or lingual aspect. O-P-B[3,18,19,24,36]: Starting posteriorly and proceeding along the occlusal aspect of the ridge to the other side, returning along the palatal or lingual aspect, and finally scanning the buccal aspect. ZZ-P[7,25]: Starting posteriorly on the occlusal aspect of the ridge alternating between the occlusal and buccal aspects in a zig-zag path along the ridge, and finally scanning the palatal or lingual aspect. ZZ[14,25]: Starting posteriorly on the buccal aspect of the ridge alternating between buccal, occlusal, and lingual aspects in a zig-zag path along the ridge, and ending on the other side for the mandible; for the maxillary arch, starting posteriorly on the buccal aspect, moving to the opposite side crossing the palate, continuing in a zig-zag path scanning the entire arch, and ending anteriorly. For all strategies, except ZZ, when scanning the palatal surface of the maxillary arch, the scanning began at the posterior aspect, proceeded along the palatal surface of the ridge reaching the other side, followed by a second narrower inverted U-shaped path in the opposite direction to cover the palate vault, and finally moving across the posterior palatal seal area to end on the contralateral side of the starting point.[22] The maxillary and mandibular typodonts were mounted on a phantom head to simulate a clinical situation during scanning. All digital scanning procedures were done by a single prosthodontist (F.Z.J.). For standardization, all samples were scanned for 1 scanning strategy per arch each day, and all scanning procedures started at the same time each day.

A metrology software program (Geomagic control X; 3D SYSTEMS) was used to analyze the accuracy of each experimental group. All samples were trimmed short of the depth of the vestibule and were individually superimposed onto the reference scan by using the best-fit algorithm applied to a specified region of interest that included the ridge area and palate for the maxillary arch and only the ridge area for the mandible. After completion of the superimposition, the distance deviation values were calculated across the entire region of interest. The root mean square (RMS) of the absolute deviation values was calculated and used to express trueness. To measure precision, the sample with the best trueness results from each group was used as a reference.[7] The remaining samples from the same group were superimposed onto the selected reference sample, as described for trueness, and the distances between the scans were calculated. The RMS of the absolute distance values within each group was obtained and used to express precision.

Data from the experiment were summarized by using means and standard deviations across all scanners, strategies, and arches. Statistical modeling was applied to the trueness and precision independently with the fixed effects models. The dependent variables for each model were trueness and precision, where the main effects were the scanner (which included the conventional impression), the strategy, and the arch. Models were tested for interaction terms between the main effects, and the covariance structure was chosen based on the Akaike information criterion (AIC). The statistical analysis was conducted with a statistical software program (SAS 9.4; SAS Institute Inc) (α=.05).

RESULTS

With regard to trueness, the fixed effects model revealed that the main effect of the scanner had a significant effect on the RMS value (P<.001). The conventional impression had the best trueness, with the lowest mean RMS value at 60.11 µm, followed closely by the TRIOS 4 scanner with a mean RMS of 69.51 µm. The Emerald S scanner had the highest mean RMS at 105.71 µm. The main effect for strategy had a significant impact on RMS values (P<.001). Strategy P-O-B produced the lowest overall mean RMS at 67.48 µm, while strategy ZZ had the highest overall mean RMS at 100.46 µm. A significant interaction was found between the scanner and the strategy (P=.012). Strategies B-O-P, ZZ-P, and ZZ had mean RMS values of 62.93 µm, 66.75 µm, and 81.46 µm, respectively, when using the TRIOS 4 scanner, which outperformed the Emerald S scanner that had mean RMS values of 127.36 µm, 131.42 µm, and 119.46 µm, respectively, for the same strategies. The main effect for arch had no significant impact on this model (P=.069), and no significant interaction was found. The data for trueness are presented in Table 1 and Figure 2.

With regard to precision, the main effect for scanner showed statistically significant results (P=.004). The TRIOS 4 scanner showed the greatest precision with the lowest mean RMS value at 73.89 µm, which was slightly lower than for the conventional impression, which had a mean RMS value of 75.56 µm. The Emerald S scanner had the highest mean RMS at 101.13 µm. The main effect for strategy demonstrated significant differences (P=.033). Strategies P-O-B and O-P-B had the lowest mean RMS values at 65.77 µm and 68.4 µm, respectively, while strategies O-B-P and ZZ had the highest mean

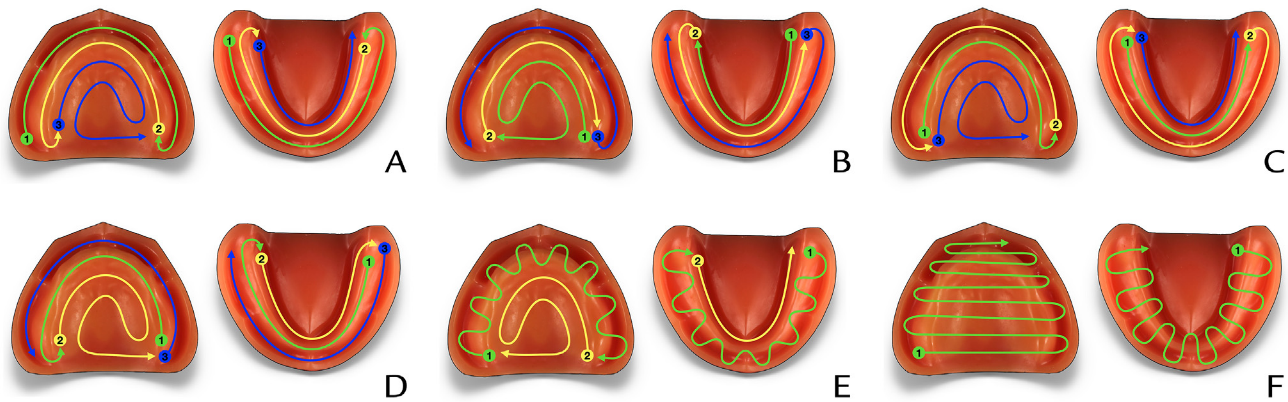

Figure 1. Scanning strategies tested. A, B-O-P. B, P-O-B. C, O-B-P. D, O-P-B. E, ZZ-P. F, ZZ.

RMS values at 103.23 μm and 103.69 μm, respectively. The main effect for arch also showed significant differences, as the maxillary arch had better precision compared with the mandibular arch (*P*=.023). No significant interactions were found between the effects in this model, including scanner by strategy (*P*=.345) or strategy by arch (*P*=.653). The data for precision are presented in Table 2 and Figure 3.

DISCUSSION

The first null hypothesis was rejected because of the significant interaction between the main effects of scanner and strategy with regard to trueness (*P*=.012). The impact of this interaction was greater with the Emerald S scanner. The second null hypothesis was also rejected because the main effect of scanner had a significant effect on both trueness (*P*<.001) and precision (*P*<.001). The accuracy of the TRIOS 4 scanner was comparable with that of the conventional impression, while the Emerald S scanner had inferior accuracy to both. Previous reports that the TRIOS scanner has better accuracy than Emerald[16,32] were confirmed in the present study despite using the enhanced Emerald S scanner. Nevertheless, the differences between scanners and strategies fell below the clinically relevant threshold of 300 μm defined by Osnes et al[16] based on deviation values of traditionally flasked dentures. Thus, the variation reported in the present study may have limited clinical impact.

The amount and arrangement of common areas needed for accurate image stitching is influenced by the scanning strategy used.[33] Scanning strategies with fewer initial common areas are likely to introduce errors in the stitching process, reducing the accuracy of the scan.[33] The impact of scanning strategies on the accuracy of digital scans has been demonstrated[18,29,31-35] and appears to be IOS specific, as different results were found when using different scanners.[31,32,34,35] The results of the present study were consistent with those of previous studies, since the accuracy of the scans was different depending on the scanner and the strategy. The previous studies, however, examined the effects of scanning strategies on dentate arches or a combination of dentition and scan bodies.[31,32,34,35] Only the Zarone et al study[18] was identified as investigating the effects of scan strategies on edentulous arches. They reported that in an edentulous maxillary arch, scanning the occlusal aspect of the ridge followed by the buccal aspect and finally the palatal aspect produced the most accurate scan, especially if the anatomy of the ridge and the rugae were well-defined.[18] Zarone et al, however, used a single IOS system and did not address the mandibular arch.[18] Their results agree with the Emerald S scanning guidelines for dentate complete arches and the TRIOS 4 guidelines for dentate maxillary complete arches recommended by the manufacturers.[36,37] The present results differed from those by Zarone et al and the manufacturer recommendations, as it was found that strategies P-O-B and O-P-B had better accuracy, regardless of the scanner used. These strategies start with either the palatal or lingual aspect or the occlusal aspect and end with the buccal aspect. For mandibular dentate complete arch scans, the TRIOS 4 manufacturer recommends starting with the occlusal aspect of the ridge followed by the lingual surface and ending with the buccal surface, similar to the O-P-B strategy described in the present study.

Currently, digital scans are recommended for single-tooth and short-span prostheses only.[1] Although complete arch digital scans for implant prostheses have been reported to produce clinically acceptable results, they are not yet recommended for clinical use for complete dentures.[30] The lack of clinical acceptance derives from error propagation during image stitching, which leads to more errors in larger scans.[16,20] Considering the larger scan area of the maxillary arch compared with the mandibular arch, mandibular scans may be thought to be more accurate. However, in the present study, no significant effect on

Table 1. Trueness results (µm): Mean RMS, median, standard deviation, standard error, upper 95% mean, and lower 95% mean

Group	Strategy	Arch	Mean RMS	Median	Standard Deviation	Standard Error Mean	Upper 95% Mean	Lower 95% Mean
Conventional	-	Maxillary	60.51	57.85	19.63	6.21	74.55	46.47
	-	Mandibular	59.70	57.75	8.02	2.54	65.44	53.96
Emerald S	B-O-P	Maxillary	161.86	154.10	48.14	15.22	196.30	127.42
		Mandibular	92.85	92.50	11.53	3.65	101.10	84.60
	P-O-B	Maxillary	62.87	62.35	12.99	4.11	72.16	53.58
		Mandibular	89.61	82.85	20.69	6.54	104.41	74.81
	O-B-P	Maxillary	106.33	88.00	58.97	18.65	148.51	64.15
		Mandibular	82.47	82.60	21.29	6.73	97.70	67.24
	O-P-B	Maxillary	86.96	84.35	17.43	5.51	99.43	74.49
		Mandibular	83.76	73.70	22.15	7.00	99.60	67.92
	ZZ-P	Maxillary	145.49	134.80	56.01	17.71	185.56	105.42
		Mandibular	117.35	108.80	44.08	13.94	148.88	85.82
	ZZ	Maxillary	118.67	113.35	44.92	14.20	150.80	86.54
		Mandibular	120.25	105.50	36.31	11.48	146.23	94.27
TRIOS 4	B-O-P	Maxillary	59.09	51.45	17.95	5.68	71.93	46.25
		Mandibular	66.76	56.85	25.60	8.09	85.07	48.45
	P-O-B	Maxillary	51.99	52.15	9.86	3.12	59.05	44.93
		Mandibular	65.45	59.30	19.45	6.15	79.36	51.54
	O-B-P	Maxillary	64.26	50.15	46.97	14.85	97.86	30.66
		Mandibular	77.38	79.00	20.96	6.63	92.37	62.39
	O-P-B	Maxillary	85.04	68.25	49.77	15.74	120.64	49.44
		Mandibular	67.67	66.40	11.38	3.60	75.81	59.53
	ZZ-P	Maxillary	61.49	66.05	11.58	3.66	69.78	53.20
		Mandibular	72.01	66.60	19.55	6.18	86.00	58.02
	ZZ	Maxillary	78.12	67.80	37.43	11.84	104.90	51.34
		Mandibular	84.81	76.85	27.22	8.61	104.28	65.34

RMS, root mean square.

the trueness of the scan between arches was found (P=.069). Although the arch did have a significant effect on the precision of the scan (P=.006), it was the maxillary arch that had better precision, possibly because of the greater amount of information and number of datapoints collected, which improved accuracy.[20] A similar observation was noted by Mizumoto et al,[20] who reported better but not statistically significant improvement in accuracy when the palate was scanned versus when not scanned.

Limitations of digital scanning for complete dentures include the inability to adequately capture the functional movements needed for border extensions.[5,18,23] Lo Russo et al[6] reported significant differences between edentulous conventional impressions and digital scans. However, no significant differences were found after trimming the unmatched peripheral tissues. Meanwhile, Chebib et al[11] reported significant differences in the intaglio seal but no significant differences in the peripheral border between PVS impressions and digital scans. A conventional recapturing of the border extensions during clinical evaluation of the denture may be needed when digital scans are used.[23,24]

Discrepancies between conventional impressions and digital scans have been attributed to mucosal compressibility.[6] This may not be of great clinical consequence, as Kang et al[27] reported no significant differences in the internal adaptation of dentures fabricated from digital or conventional impressions. Moreover, in situations of considerable tissue mobility, digital impressions may be advantageous as true mucostatic impressions can be acquired.[3,6,9,24] The intimate contact between the denture fitting surface and the mucosa achieved with digital scans has led some authors to understate the importance of a peripheral seal.[9,27] However, significantly reduced retention, likely caused by border inaccuracies and poor seal, has been reported with dentures produced from digital scans.[26] Nevertheless, without a minimum retention threshold, the retention of dentures produced from digital scans might still be clinically acceptable.[26] Despite these limitations, fully digital denture fabrication workflows have been clinically demonstrated and suggested as a suitable alternative to conventional methods.[3,9,23-25,27]

Limitations of this study included its in vitro design. Thermal changes between the intraoral environment and room temperature result in dimensional changes of PVS impressions.[8] This was not accounted for in this study and may have led to overestimating the accuracy of PVS impressions. The compressibility of the model used in this study differs from that of intraoral tissues. The compressibility of intraoral tissues can produce differences between conventional impressions and digital scans

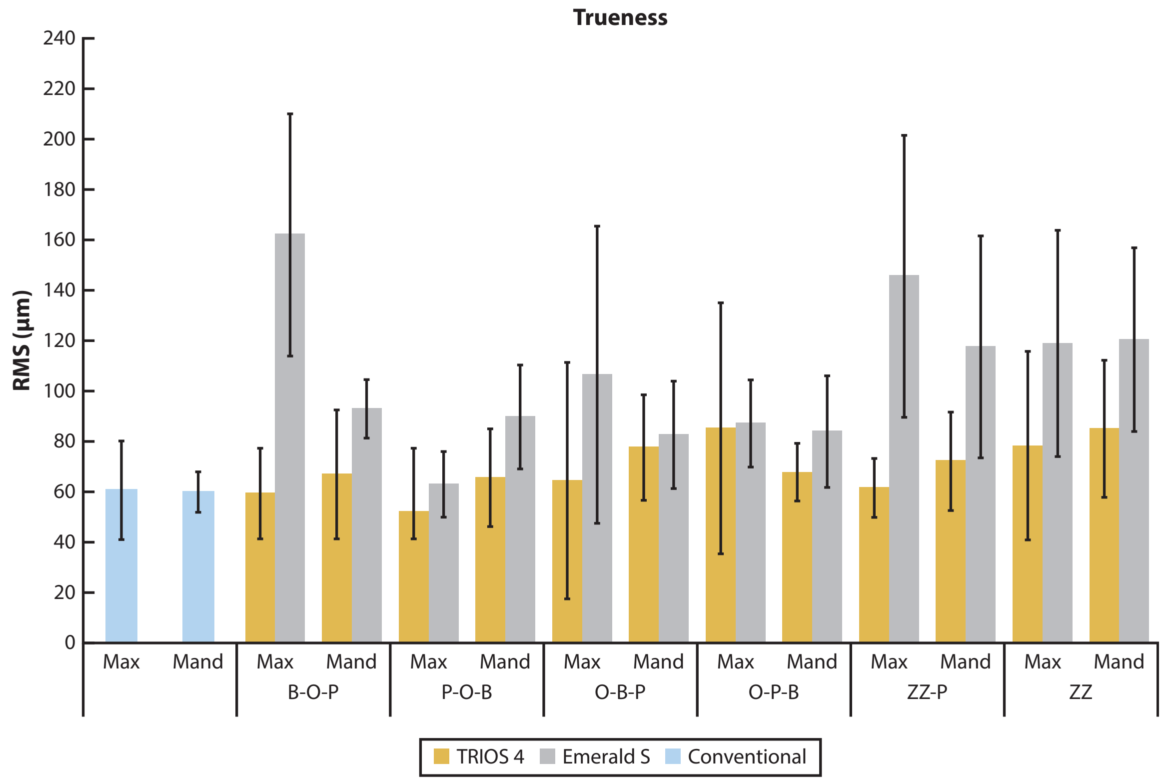

Figure 2. Trueness mean RMS values (µm) for each scanner, strategy, and arch. Error bars present ±standard deviation. RMS, root mean square.

Table 2. Precision results (µm): Mean RMS, median, standard deviation, standard error, upper 95% mean, and lower 95% mean

Group	Strategy	Arch	Mean RMS	Median	Standard Deviation	Standard Error Mean	Upper 95% Mean	Lower 95% Mean
Conventional	-	Maxillary	68.58	63.70	28.95	9.65	90.83	46.32
	-	Mandibular	82.53	83.90	19.52	6.51	97.54	67.53
Emerald S	B-O-P	Maxillary	121.17	133.40	48.45	16.15	158.41	83.92
		Mandibular	115.60	105.60	44.58	14.86	149.87	81.33
	P-O-B	Maxillary	52.04	48.20	14.35	4.78	63.08	41.01
		Mandibular	102.29	95.10	31.67	10.56	126.63	77.95
	O-B-P	Maxillary	116.14	99.10	65.10	21.70	166.19	66.10
		Mandibular	138.47	145.00	17.68	5.89	152.06	124.88
	O-P-B	Maxillary	54.06	52.80	10.01	3.34	61.75	46.36
		Mandibular	79.44	65.30	27.30	9.10	100.43	58.46
	ZZ-P	Maxillary	100.70	85.10	52.19	17.40	140.82	60.58
		Mandibular	107.50	82.40	59.52	19.84	153.25	61.75
	ZZ	Maxillary	110.49	103.70	44.11	14.70	144.39	76.58
		Mandibular	115.64	114.20	46.59	15.53	151.46	79.83
TRIOS 4	B-O-P	Maxillary	55.76	57.10	18.26	6.09	69.79	41.72
		Mandibular	106.91	94.20	40.49	13.50	138.03	75.79
	P-O-B	Maxillary	36.19	36.20	8.45	2.82	42.69	29.69
		Mandibular	72.56	66.30	28.49	9.50	94.46	50.65
	O-B-P	Maxillary	66.51	52.50	56.55	18.85	109.98	23.04
		Mandibular	91.81	77.60	34.11	11.37	118.03	65.59
	O-P-B	Maxillary	79.13	47.80	66.04	22.01	129.89	28.37
		Mandibular	60.97	59.40	15.26	5.09	72.70	49.24
	ZZ-P	Maxillary	62.97	64.20	6.62	2.21	68.06	57.88
		Mandibular	65.31	64.40	28.55	9.52	87.26	43.36
	ZZ	Maxillary	77.84	69.30	42.70	14.23	110.67	45.02
		Mandibular	110.77	95.40	38.23	12.74	140.16	81.38

RMS, root mean square.

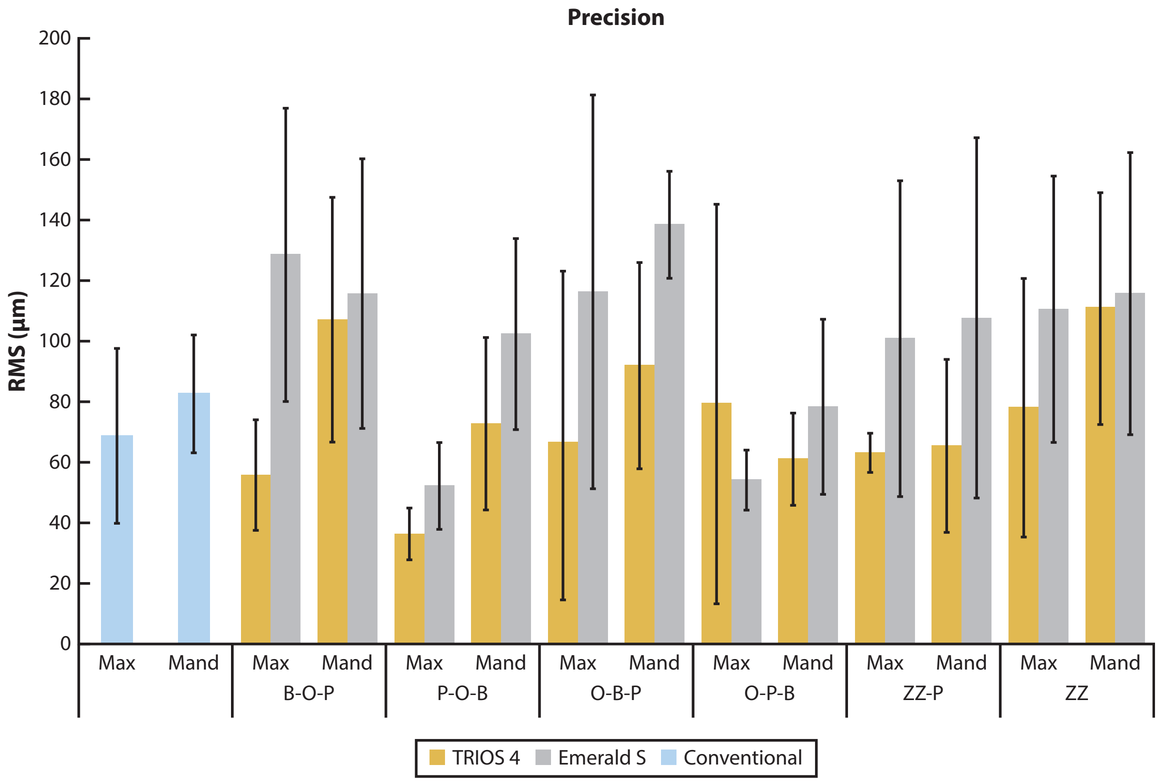

Figure 3. Precision mean RMS values (µm) for each scanner, strategy, and arch. Error bars present ±standard deviation. RMS, root mean square.

clinically.[6] Because of the reported difficulties of scanning border tissues[11,18] and the static nature of the model used in this study, the borders were not considered in the accuracy analysis. The presence of saliva may further impact the accuracy of the digital scans.[11,15] However, obtaining a high accuracy reference for trueness evaluation is not possible clinically. As such, in vivo accuracy studies can compare techniques and address precision without referring to trueness.[11,14] The current study only investigated 2 IOS systems with different scanning mechanisms. Different results may be found with other scanning systems. Furthermore, only 6 scanning strategies were investigated. Other strategies may be devised which lead to different outcome in terms of scan accuracy. The operator experience may also impact the accuracy of intraoral scans; this was not considered, as only 1 experienced operator performed the experiment.[12,33] Clinical research is needed to identify the implications of the findings of this study and show how they relate to the completely digital workflow for complete denture fabrication.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The type of scanner and scanning strategy had a significant effect on the trueness and precision of the digital scans of completely edentulous arches.
2. A significant interaction was found between scanner and strategy with regard to the trueness of completely edentulous arches.
3. The arch being scanned had a significant effect on the precision of the digital scans of completely edentulous arches, with the maxillary arch showing better precision than the mandibular arch. However, the arch had no significant effect on trueness.
4. The TRIOS 4 scanner showed accuracy levels comparable with those of conventional impressions, both of which were better than the Emerald S scanner.
5. Strategy P-O-B had the best overall accuracy, and strategy F had the poorest overall accuracy when scanning completely edentulous arches.

REFERENCES

1. Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital versus conventional impressions in fixed prosthodontics: a review. *J Prosthodont*. 2018;27:35-41.
2. Lee DJ, Saponaro PC. Management of edentulous patients. *Dent Clin North Am*. 2019;63:249-261.
3. Goodacre BJ, Goodacre CJ, Baba NZ. Using intraoral scanning to capture complete denture impressions, tooth positions, and centric relation records. *Int J Prosthodont*. 2018;31:377-381.
4. Gutmacher Z, Kelly A, Renne W, et al. Evaluation of the accuracy of multiple digital impression systems on a fully edentulous maxilla. *Quintessence Int*. 2021;52:488-495.
5. Zarone F, Ruggiero G, Ferrari M, Mangano F, Joda T, Sorrentino R. Accuracy of a chairside intraoral scanner compared with a laboratory scanner for the completely edentulous maxilla: an in vitro 3-dimensional comparative analysis. *J Prosthet Dent*. 2020;124:761.e1-761.e7.

6. Lo Russo L, Caradonna G, Troiano G, Salamini A, Guida L, Ciavarella D. Three-dimensional differences between intraoral scans and conventional impressions of edentulous jaws: a clinical study. *J Prosthet Dent*. 2020;123:264–268.
7. Tao C, Zhao YJ, Sun YC, Heng MD, Xie QF, Pan SX. Accuracy of intraoral scanning of edentulous jaws with and without resin markers. *Chin J Dent Res*. 2020;23:265–271.
8. Kim KM, Lee JS, Kim KN, Shin SW. Dimensional changes of dental impression materials by thermal changes. *J Biomed Mater Res*. 2001;58:217–220.
9. Lo Russo L, Salamini A. Single-arch digital removable complete denture: a workflow that starts from the intraoral scan. *J Prosthet Dent*. 2018;120:20–24.
10. Rasaie V, Abduo J, Hashemi S. Accuracy of intraoral scanners for recording the denture bearing areas: a systematic review. *J Prosthodont*. 2021;30:520–539.
11. Chebib N, Kalberer N, Srinivasan M, Maniewicz S, Perneger T, Müller F. Edentulous jaw impression techniques: an in vivo comparison of trueness. *J Prosthet Dent*. 2019;121:623–630.
12. Schimmel M, Akino N, Srinivasan M, Wittneben JG, Yilmaz B, Abou-Ayash S. Accuracy of intraoral scanning in completely and partially edentulous maxillary and mandibular jaws: an in vitro analysis. *Clin Oral Investig*. 2021;25:1839–1847.
13. Patzelt SB, Vonau S, Stampf S, Att W. Assessing the feasibility and accuracy of digitizing edentulous jaws. *J Am Dent Assoc*. 2013;144:914–920.
14. Hack G, Liberman L, Vach K, Tchorz JP, Kohal RJ, Patzelt SBM. Computerized optical impression making of edentulous jaws - An in vivo feasibility study. *J Prosthodont Res*. 2020;64:444–453.
15. Tasaka A, Uekubo Y, Mitsui T, et al. Applying intraoral scanner to residual ridge in edentulous regions: in vitro evaluation of inter-operator validity to confirm trueness. *BMC Oral Health*. 2019;19:264.
16. Osnes CA, Wu JH, Venezia P, Ferrari M, Keeling AJ. Full arch precision of six intraoral scanners in vitro. *J Prosthodont Res*. 2020;64:6–11.
17. Jung S, Park C, Yang HS, et al. Comparison of different impression techniques for edentulous jaws using three-dimensional analysis. *J Adv Prosthodont*. 2019;11:179–186.
18. Zarone F, Ruggiero G, Ferrari M, Mangano F, Joda T, Sorrentino R. Comparison of different intraoral scanning techniques on the completely edentulous maxilla: an in vitro 3-dimensional comparative analysis. *J Prosthet Dent*. 2020;124:762.e1–762.e8.
19. Li J, Moon HS, Kim JH, Yoon HI, Oh KC. Accuracy of impression-making methods in edentulous arches: An in vitro study encompassing conventional and digital methods. *J Prosthet Dent*. 2022;128:479–486.
20. Mizumoto RM, Alp G, Özcan M, Yilmaz B. The effect of scanning the palate and scan body position on the accuracy of complete-arch implant scans. *Clin Implant Dent Relat Res*. 2019;21:987–994.
21. Fang JH, An X, Jeong SM, Choi BH. Digital intraoral scanning technique for edentulous jaws. *J Prosthet Dent*. 2018;119:733–735.
22. Zhongpeng Y, Tianmin X, Ruoping J. Deviations in palatal region between indirect and direct digital models: an in vivo study. *BMC Oral Health*. 2019;19:66.
23. Unkovskiy A, Wahl E, Zander AT, Huettig F, Spintzyk S. Intraoral scanning to fabricate complete dentures with functional borders: a proof-of-concept case report. *BMC Oral Health*. 2019;19:46.
24. Goodacre BJ, Goodacre CJ. Using intraoral scanning to fabricate complete dentures: first experiences. *Int J Prosthodont*. 2018;31:166–170.
25. Fang JH, An X, Jeong SM, Choi BH. Development of complete dentures based on digital intraoral impressions-Case report. *J Prosthodont Res*. 2018;62:116–120.
26. Chebib N, Imamura Y, El Osta N, Srinivasan M, Müller F, Maniewicz S. Fit and retention of complete denture bases: Part II - conventional impressions versus digital scans: a clinical controlled crossover study. *J Prosthet Dent*. 30 August 2022. https://doi.org/10.1016/j.prosdent.2022.07.004 [Epub ahead of print.].
27. Kang YJ, Oh KC, Kim GY, Moon HS. Comparative evaluation of digitally fabricated complete dentures versus conventional complete dentures: a randomized, single-blinded, cross-over clinical trial. *J Prosthet Dent*. 9 September 2022. https://doi.org/10.1016/j.prosdent.2022.05.013 [Epub ahead of print.].
28. International Organization for Standardization. ISO 5725-1. Accuracy (trueness and precision) of measurement methods and results. Part 1: general principles and definitions. Berlin: International Organization for Standardization. 1994. Available at: https://www.iso.org/standard/11833.html.
29. Oh KC, Park JM, Moon HS. Effects of scanning strategy and scanner type on the accuracy of intraoral scans: a new approach for assessing the accuracy of scanned data. *J Prosthodont*. 2020;29:518–523.
30. Papaspyridakos P, Vazouras K, Chen YW, et al. Digital vs conventional implant impressions: A systematic review and meta-analysis. *J Prosthodont*. 2020;29:660–678.
31. Medina-Sotomayor P, Pascual-Moscardó A, Camps I. Accuracy of four digital scanners according to scanning strategy in complete-arch impressions. *PLoS One*. 2018;13:e0202916.
32. Latham J, Ludlow M, Mennito A, Kelly A, Evans Z, Renne W. Effect of scan pattern on complete-arch scans with 4 digital scanners. *J Prosthet Dent*. 2020;123:85–95.
33. Gavounelis NA, Gogola CC, Halazonetis DJ. The effect of scanning strategy on intraoral scanner's accuracy. *Dent J (Basel)*. 2022;10:123.
34. Passos L, Meiga S, Brigagão V, Street A. Impact of different scanning strategies on the accuracy of two current intraoral scanning systems in complete-arch impressions: an in vitro study. *Int J Comput Dent*. 2019;22:307–319.
35. Son K, Jin MU, Lee KB. Feasibility of using an intraoral scanner for a complete-arch digital scan, part 2: a comparison of scan strategies. *J Prosthet Dent*. 22 June 2021. https://doi.org/10.1016/j.prosdent.2021.05.021 [Epub ahead of print.].
36. 3Shape. TRIOS® Module User Manual. TRIOS-1.18.5-C-EN. Available at: https://3shape.widen.net/view/pdf/vdaf6vgd5g/TRIOS-Module-User-Manual-1.18.5-C-EN.pdf?t.download=true&u=6xmdhr. Accessed September 18, 2022.
37. Planmeca. Planmeca Emerald® & Planmeca Emerald S® user's manual. Available at: https://materialbank.planmeca.com/catalog/Manuals/r/221906/viewmode=previewview/qsr=Planmeca%20Emerald%20S/fc=5%3A1. Accessed September 18, 2022.
38. Lee JH. Improved digital impressions of edentulous areas. *J Prosthet Dent*. 2017;117:448–449.
39. Chaffee NR, Cooper LF, Felton DA. A technique for border molding edentulous impressions using vinyl polysiloxane material. *J Prosthodont*. 1999;8:129–134.

Corresponding author:
Dr Faris Z. Jamjoom
Restorative and Prosthetic Dental Science Department, College of Dentistry
King Saud Bin Abdulaziz University for Health Sciences
Prince Mutib Ibn Adbullah Ibn Abdulaziz Rd, Ar Rimayah
Riyadh, 14611
SAUDI ARABIA
Email: jamjoomf@ksau-hs.edu.sa

https://doi.org/10.1016/j.prosdent.2023.01.027