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ORIGINAL ARTICLE

In vitro evaluation of the impact of intraoral scanner, scanning aids, and the scanned arch on the scan accuracy of edentulous arches

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Abstract

Purpose: To assess the accuracy of complete maxillary and mandibular edentulous arch scans obtained using two different intraoral scanners (IOSs), with and without scanning aids, and to compare these results to those obtained using conventional impression methods.

Materials and Methods: Two IOSs were used (TRIOS 4 [TRI] and Emerald S [EMR]) to scan maxillary and mandibular typodonts. The typodonts were scanned without scanning aids [TRI_WSA and EMR_WSA groups] ($n = 10$). The typodonts were then scanned under four scanning aid conditions ($n = 10$): composite markers [TRI_MRK and EMR_MRK groups], scanning spray [TRI_SPR and EMR_SPR groups], pressure indicating paste [TRI_PIP and EMR_PIP groups], and liquid-type scanning aid [TRI_LQD and EMR_LQD groups]. Conventional impressions of both arches were also made using irreversible hydrocolloids in stock trays [IHC] and using polyvinyl siloxane (PVS) impression material in custom trays ($n = 10$) which were digitized using a laboratory scanner. Using a metrology software program, all scans were compared to a reference scan in order to assess trueness and to each other to assess precision. Trueness and precision were expressed as the root mean square (RMS) of the absolute deviation values and the statistical analysis was modeled on a logarithmic scale using fixed-effects models to meet model assumptions ($\alpha = 0.05$).

Results: The main effect of arch ($p = 0.004$), scanner ($p < 0.001$), scanning aid ($p = 0.041$), and the interaction between scanner and scanning aid ($p = 0.027$) had a significant effect on mean RMS values of trueness. The arch ($p = 0.015$) and scanner ($p < 0.001$) had a significant effect on the mean RMS values of precision. The maxillary arch had better accuracy compared to the mandible. The TRIOS 4 scanner had better accuracy than both the Emerald S scanner and conventional impressions. The Emerald S had better precision than conventional impressions. The scanning spray and liquid-type scanning aids produced the best trueness with the TRIOS 4 scanner, while the liquid-type scanning aid and composite markers produced the best trueness for the Emerald S scanner.

Conclusion: The scanned arch and the type of scanner had a significant effect on the accuracy of digital scans of completely edentulous arches. The scanning aid had a significant effect on the trueness of digital scans of completely edentulous arches which varied depending on the scanner used.

KEYWORDS
digital impression, edentulous arch, intraoral scanner, scan accuracy, scanning aids

Conventional complete denture fabrication protocols start with preliminary impressions using various impression materials in stock trays.[1] These materials include irreversible hydrocolloids, silicone putty, or impression compound, with Alginate being the most widely used.[1,2] These are followed by final impressions that involve the use of custom trays with elastomeric impression materials which can be done in either a single step or two separate steps.[1,3] The two-step procedure continues to be the gold standard for complete denture fabrication; the first step captures the functional border with modeling compound, and the second step captures the fitting surface with the selected impression material.[3] Polyvinylsiloxane (PVS) has also been described as an alternative to compound for border molding procedures with comparable results.[4,5] Simplified protocols for complete denture fabrication using a single irreversible hydrocolloid impression in a stock tray have been proposed to reduce cost and time.[6,7] Although higher patient satisfaction is reported with the conventional protocol there seems to be no significant differences overall between the two methods.[6,7]

Regardless of the protocol, conventional complete denture fabrication is a time-consuming process that can introduce errors due to distortion of the impression material, dental stone, and heat-polymerized acrylic resin.[8–11] To overcome the errors associated with conventional methods and to simplify the process computer-aided design and computer-aided manufacturing (CAD-CAM) systems have been adopted for complete denture fabrication.[12] However, current CAD-CAM denture protocols still rely on the digitization of conventional impressions or stone casts.[11,12] This does not eliminate the problems associated with conventional impressions including patient gagging and discomfort, dimensional changes of the impression material and stone, and the need for storage space for the physical impression or cast.[9–11]

Digital scans using intraoral scanners (IOSs) have the potential to address some of the problems associated with conventional impressions and have proven to be more time-efficient and better accepted by patients and clinicians.[13–16] However, the accuracy of digital scans of completely edentulous arches has been questioned due to the lack of anatomical variation and reference points and the presence of large smooth areas which can produce errors in the image-stitching process.[17–23] Furthermore, there is difficulty in capturing tissues in function or under compression which may produce errors in the denture borders and peripheral seal.[3,15,23] As a result, intraoral digital scans are not yet recommended for regular use with edentulous patients.[3,17]

According to International Organization for Standardization (ISO) standard 5725-1, accuracy includes the evaluation of both trueness and precision.[24] How close a tested sample is to an accepted reference is referred to as trueness, and how close repeated measurements of a sample agree with each other is referred to as precision.[24] The reported accuracy levels of edentulous arch scans were comparable with conventional impressions; however, considerable variability has also been reported.[3,11,17–19,25–31] Furthermore, the accuracy of edentulous arch scans is affected by the IOS used, the strategy followed, and the arch being scanned.[22,31,32] Nevertheless, completely digital workflows for the fabrication of complete dentures have been reported.[15,16,33–35]

Several methods and techniques have been proposed to reduce image-stitching errors and improve the accuracy of digital scans in edentulous regions including the addition of artificial landmarks,[10,15,36–40] application of scanning spray,[15,41–43] application of pressure-indicating paste (PIP),[15,36,44] and application of liquid-type scanning aid material.[42,43] Although studies investigating the effects of scanning aids on the accuracy of digital scans are available, most evaluate partially edentulous arches or completely edentulous arches with scan bodies.[36,38–40,45] Furthermore, studies evaluating completely edentulous arches focus mainly on a single technique or method.[10,19] Therefore, the aim of this study is to evaluate the accuracy of complete maxillary and mandibular edentulous arch scans obtained using two different IOSs, with and without scanning aids, and to compare these results to those obtained using conventional impression methods. The null hypotheses were that, for each IOS, the scanning aid 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 methods.

MATERIALS AND METHODS

A pair of maxillary and mandibular edentulous typodonts with artificial mucosa (EDE1001-UL-UP-M; Nissin Dental Products Inc) were used in this study. Reference scans of the maxillary and mandibular typodonts, saved in standard tessellation language (STL) format, were obtained by scanning the typodonts using an ISO 12836 compliant dental laboratory scanner (E4; 3Shape A/S) with an accuracy of 4 μm. To simulate a clinical situation, the maxillary and mandibular typodonts were mounted on a phantom head for all impression and scanning procedures.

Ten impressions of the maxillary and mandibular arches were made at room temperature with irreversible hydrocolloid impression material (Alginmajor; Major Prodotti Dentari S.P.A.) in an edentulous stock tray according to the manufacturer's instructions. These impressions were digitized using the same laboratory scanner and saved in STL format (IHC group). The impressions were subsequently poured in ISO type III dental stone and the casts were used to fabricate custom trays.[4] The custom trays were fabricated with an extension 2 mm short of the vestibule and peripheral relief as previously described by Chaffee et al.[4] Ten PVS impressions

FIGURE 1 (a) The maxillary and mandibular typodonts without scanning aids (TRI_WSA and EMR_WSA groups). (b) Maxillary and mandibular typodonts with attached markers (TRI_MRK and EMR_MRK groups). (c) Maxillary and mandibular typodonts coated with scanning spray (TRI_SPR and EMR_SPR groups). (d) Maxillary and mandibular typodonts with irregular shapes drawn using PIP (TRI_PIP and EMR_PIP groups). (e) Maxillary and mandibular typodonts coated with a liquid-type scanning aid (TRI_LQD and EMR_LQD groups). EMR, Emerald S; IHC, irreversible hydrocolloids in stock trays; LQD, liquid-type scanning aid; MRK, composite markers; PIP, pressure indicating paste; PVS, polyvinyl siloxane; RMS, root mean square; SPR, scanning spray; TRI, TRIOS 4; WSA, without any scanning aids.

of the maxillary and mandibular arches were made at room temperature using the selective-pressure method as described previously where the peripheral borders of the typodonts were impressed using heavy-body material (Any-Flex Heavy; MEDICLUS Co., Ltd.) followed by a wash made with a light-body material (Any-Flex Light; MEDICLUS Co, Ltd).[4] These impressions were also digitized using the same laboratory scanner and saved in STL format (PVS group).

Digital scanning was carried out by a single experienced prosthodontist (F.Z.J.). For standardization, all samples from one group were scanned each day, and all scanning procedures started at the same time of the day in the same location under room light with no natural or dental chair light. Two intraoral scanners with different scanning mechanisms were used (TRIOS 4; 3Shape A/S) (Emerald S; Planmeca OY). Both scanners were calibrated according to the manufacturer prior to scanning and all scans were made following a previously proposed scanning strategy[31] that starts posteriorly and proceeds along the palatal or lingual aspect of the ridge, returning along the occlusal aspect, and finally scanning the buccal aspect. Scanning the palatal surface of the maxillary arch 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 moved across the posterior palatal seal area to end on the contralateral side of the starting point.[33] Ten scans of the maxillary and mandibular typodonts without any scanning aids were made using both the TRIOS 4 scanner (TRI_WSA group) and Emerald S scanner (EMR_WSA group) (Figure 1a).

Spherical markers around 3 mm in diameter made from flowable composite resin (GradioSo Heavy Flow; VOCO GmbH) were attached to the mucosa of the edentulous typodonts. In the maxillary arch, six markers were attached to the palatal mucosa.[10,37] While in the mandibular arch, two markers were attached to the buccal shelf on each side[10] and another two markers were attached to the lingual slope of the ridge on either side of the midline (Figure 1b). Ten scans of each arch were made using both scanners (TRI_MRK group and EMR_MRK group). The composite markers were removed and both typodonts were coated with one layer of scanning spray (CEREC Optispray; Dentsply Sirona) according to the manufacturer's instructions (Figure 1c). Scans of each arch were made and repeated 10 times using both scanners (TRI_SPR group and EMR_SPR group). The typodonts were then cleaned using an organic solvent and a

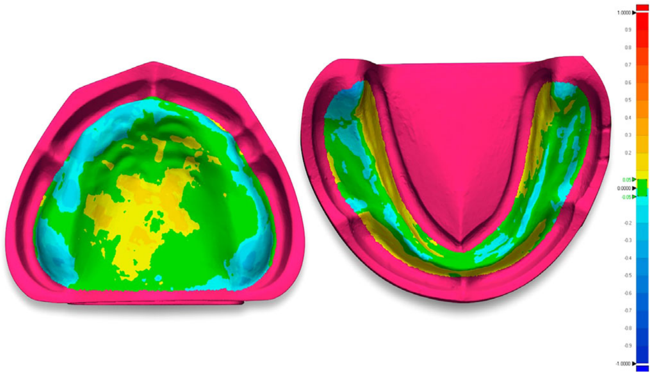

FIGURE 2 Superimposition of a representative sample to the reference scan and distance deviation measurement for trueness.

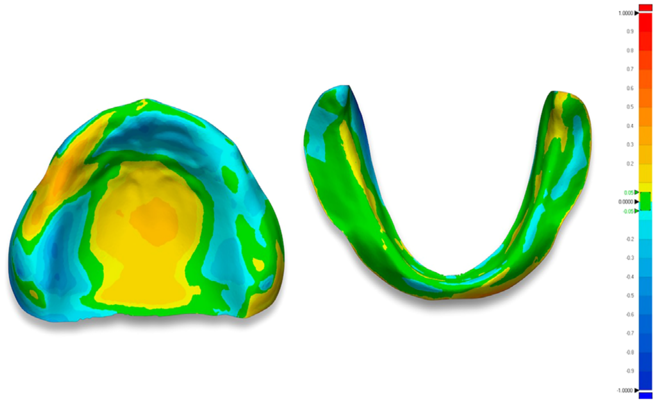

FIGURE 3 Superimposition of a representative sample to the reference scan and distance deviation measurement for precision.

steam cleaner and left to dry. Once dried, irregular shapes were drawn on the residual ridge using PIP (HI SPOT Pressure Indicator Paste; Bosworth Company) and a microbrush. The irregular shapes were connected with lines towards the center of the palate in the maxillary arch[44] and with a continuous line at the crest of the ridge in the mandibular arch (Figure 1d). The arches were scanned 10 times using each scanner (TRI_PIP group and EMR_PIP group). The typodonts were cleaned again as described previously and coated with one layer of a liquid-type scanning aid material (Scan Cure; ODS Co., Ltd.) using a brush according to the manufacturer's instructions (Figure 1e).[42,43] Each arch was scanned 10 times using both scanners (TRI_LQD group and EMR_LQD group).

All digital scans were saved in STL format prior to accuracy analysis. The accuracy analysis followed a previously described method.[31] The scan accuracy of each experimental group was analyzed using a metrology software program (Geomagic control X; 3D SYSTEMS). All samples were trimmed 1 mm short of the depth of the vestibule and the composite markers were removed from groups TRI_MRK and EMR_MRK. To evaluate trueness, each sample was individually superimposed onto the reference scan using the best-fit algorithm applied to specific areas of interest that included the edentulous ridge for the mandible and the edentulous ridge and palate for the maxillary arch. Once the superimposition was completed, the distance deviation was measured across the whole scan (Figure 2). Trueness was expressed as the root mean square (RMS) of the absolute deviation values. To evaluate precision, the sample with the smallest RMS value from each group was considered the reference.[10] The remaining samples from each group were individually superimposed onto their corresponding reference sample, as described for trueness, and the distance deviation values between the scans were calculated (Figure 3). Precision was expressed as the RMS of the absolute deviation values between the scans.

Means and standard deviation values across all techniques, scanners, and arches were summarized. Trueness and precision were modeled on a logarithmic scale using fixed-effects models to meet model assumptions. The models included main effects and interaction terms for scanner, scanning aid, and arch. The compound symmetry (CS) covariance structure was used to model the within-subject data. Post hoc comparisons were conducted using Tukey's HSD test to adjust *p*-values for multiple comparisons. Cohen's *d* was used as the measure of the effect size to support the significance of the findings. The statistical analysis was conducted with a statistical software program (SAS 9.4; SAS Institute Inc) ($\alpha = 0.05$).

RESULTS

The data for trueness and precision are presented separately in Tables 1 and 2, and Figures 4 and 5. In each segment, the impact of the main effects of arch, scanner, scanningaid, and any interactions are reported. The relevant findings for each scanner with various scanning aids are also listed.

With regards to trueness, the fixed effects model showed that the main effect of arch ($p = 0.004$) had a significant impact on the mean RMS values. The maxillary arch had an overall mean RMS value of 59.3 μm while the mandibular arch had a mean RMS value of 65.5 μm. The main effects of scanner ($p < 0.001$), scanningaid ($p = 0.041$), and their interaction ($p = 0.027$) also had a significant effect on mean RMS values. The TRIOS 4 scanner had the lowest overall mean RMS values at 47.3 μm, which was significantly lower than both conventional methods ($p = 0.001$) and the Emerald S scanner ($p < 0.001$). The conventional methods had a mean RMS value of 69.5 μm, which was not significantly lower than the Emerald S scanner at 74.7 μm ($p = 0.571$). No significant differences were found between IHC and PVS conventional impressions, which had mean RMS values of 72.6 and 66.4 μm, respectively ($p = 1.00$).

Within the TRIOS 4 scanner, TRI_SPR presented the lowest mean RMS value at 40.3 μm, which was only significantly different from TRI_PIP ($p = 0.03$). This was followed by TRI_LQD at 42.4 μm, which was also significantly different from TRI_PIP ($p = 0.042$). TRI_MRK and TRI_WSA had mean RMS values of 43.3 and 46.3 μm, respectively, which were not significantly different from any of the other groups ($p > 0.056$) ($p > 0.113$). TRI_PIP had the highest mean RMS

TABLE 1 Trueness results (in μm): Mean RMS, median, standard deviation, minimum, and maximum.

Scanner	Scanning aid/Material	Mean	Std Dev	Minimum	Maximum
CON	IHC	72.6	31.4	39.2	192.7
	PVS	66.4	15.8	41.8	95.3
EMR	WSA	75.5	23	58.2	138.6
	MRK	67.7	11.5	51.3	99.2
	SPR	91.2	45.5	54	229.1
	PIP	73.3	11.4	53.3	100.1
	LQD	65.6	12.8	47.2	93.3
TRI	WSA	46.3	18.5	29.3	102.5
	MRK	43.3	14.7	29.2	91.5
	SPR	40.3	6.5	29.9	53.1
	PIP	64.3	12	49.4	82.9
	LQD	42.4	14.6	29.4	93.8

Abbreviations: EMR, Emerald S; IHC, irreversible hydrocolloids in stock trays; LQD, liquid-type scanning aid; MRK, composite markers; PIP, pressure indicating paste; PVS, polyvinyl siloxane; RMS, root mean square; SPR, scanning spray; TRI, TRIOS 4; WSA, without any scanningaids.

TABLE 2 Precision results (in μm): Mean RMS, median, standard deviation, minimum, and maximum.

Scanner	Scanning aid/Material	Mean	Std Dev	Minimum	Maximum
CON	IHC	169.3	100.6	53.4	381.6
	PVS	112	41.5	49.6	197.9
EMR	WSA	46.1	25.8	22	104.9
	MRK	66.6	26.1	35.8	148.6
	SPR	99.3	50.5	26.1	233.1
	PIP	57.3	21.5	29.5	102.5
	LQD	59.5	37	22.7	171.3
TRI	WSA	47.6	29.8	16.1	121.1
	MRK	68.3	33.5	20.4	141.7
	SPR	58.8	24.9	17.6	102.2
	PIP	33	17.1	16	64.3
	LQD	39.4	27.1	10	116.5

Abbreviations: EMR, Emerald S; IHC, irreversible hydrocolloids in stock trays; LQD, liquid-type scanning aid; MRK, composite markers; PIP, pressure indicating paste; PVS, polyvinyl siloxane; RMS, root mean square; SPR, scanning spray; TRI, TRIOS 4; WSA, without any scanningaids.

value at 64.3 μm. TRI_SPR, TRI_LQD, and TRI_MRK were significantly lower than both IHC ($p < 0.017$) and PVS ($p < 0.041$) impressions. TRI_WSA was significantly lower than IHC ($p = 0.035$) but not PVS ($p = 0.083$). TRI_PIP was not significantly different from IHC ($p = 0.999$) or PVS ($p = 1.00$).

Within the Emerald S scanner, EMR_LQD had the lowest mean RMS value at 65.7 μm followed closely by EMR_MRK at 67.7 μm. EMR_PIP and EMR had mean RMS values of 73.3 and 75.5 μm, respectively. EMR_SPR had the highest mean RMS value at 91.2 μm. No significant differences

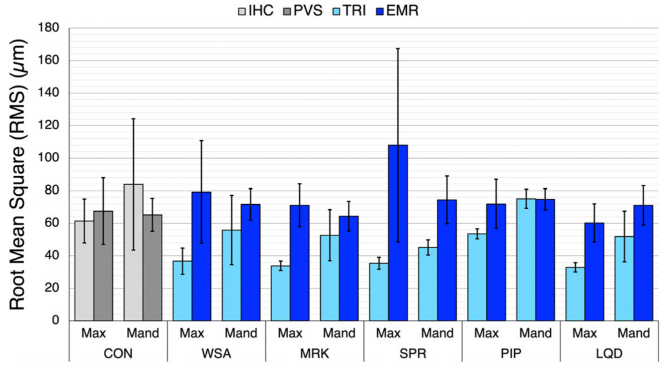

FIGURE 4 Trueness mean RMS values (μm) for each scanner, scanningaid, and arch. Error bars present ± standard deviation. RMS, root mean square.

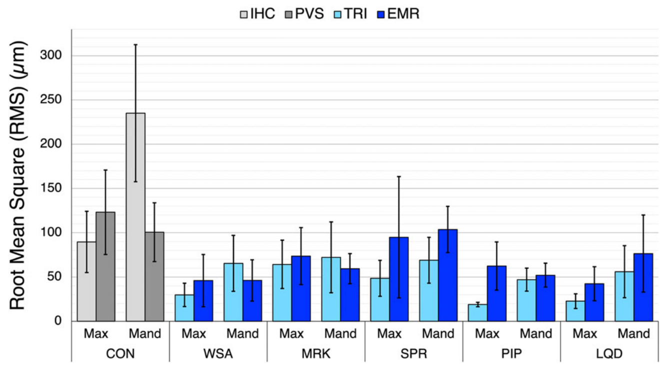

FIGURE 5 Precision mean RMS values (μm) for each scanner, scanningaid, and arch. Error bars present ± standard deviation. RMS, root mean square.

were found between any of the groups ($p > 0.464$), nor were there any significant differences when compared to IHC ($p > 0.776$) or PVS ($p > 0.473$). When comparing both scanners using the same scanning aid, TRIOS 4 had significantly lower mean RMS values for all scanning aids ($p < 0.032$) except for TRI_PIP and EMR_PIP which were not significantly different ($p = 0.969$).

With regards to precision, the main effect of arch ($p = 0.015$) had a significant effect on the mean RMS values. The maxillary arch had an overall mean RMS value of 59.7 μm while the mandibular arch had a mean RMS value of 82 μm. The main effect of scanner ($p < 0.001$) also had a significant effect on mean RMS values. The TRIOS 4 scanner had the lowest overall mean RMS values at 49.4 μm which was significantly lower than both conventional methods ($p = 0.002$) and the Emerald S scanner ($p = 0.039$). The Emerald S scanner had a mean RMS value of 65.8 μm which was significantly lower than conventional methods at 140.6 μm ($p = 0.002$). No significant differences were found between IHC and PVS conventional impressions ($p = 0.346$). The main effect of scanning aid did not have a significant impact on mean RMS values ($p = 0.099$) nor were any significant interactions found ($p = 0.571$).

DISCUSSION

The first null hypothesis was rejected because the main effects of arch ($p = 0.004$), scanner ($p < 0.001$), scanningaid ($p = 0.041$), and the interaction between scanner and scanning aid ($p = 0.027$) had a significant impact on the trueness of digital scans of completely edentulous arches. In addition, the main effects of arch ($p = 0.015$) and scanner ($p < 0.001$) had a significant impact on the precision of digital scans of completely edentulous arches.

It is generally understood that scanning larger areas and longer spans is more likely to introduce errors as the image stitching increases.[20] As such, mandibular scans might be expected to have better accuracy. However, several studies have demonstrated either similar accuracy or even better accuracy with the maxillary arch.[18,25,31] In the present study, the maxillary arch scans were significantly more accurate on average. This may be due to the greater number of data points collected and the variation provided by the rugae.[20,23,26,31] However, the depth of the palatal vault and the degree of rugae definition may influence the accuracy of the scan.[21,23] Selecting the appropriate scanning strategy would be necessary to overcome these issues.[21,46] Nevertheless, the difference in mean RMS values, which was roughly 6 μm, for each arch is small relative to the size of the arch. Therefore, the difference may not be considered clinically significant.

The IOS technology influences the accuracy of digital scans, with generally high accuracy levels reported with the TRIOS scanners.[22,26,28,31,32] These scanners also demonstrated high accuracy when scanning edentulous maxillae.[22,28,31] In the present study, the TRIOS 4 was more accurate than both conventional impressions and the Emerald S scanner. TRIOS scanners use confocal microscopy imaging as opposed to the projected pattern triangulation used in Emerald S, which might be more suitable for scanning soft tissues compared to some triangulation methods.[22,26,32]

Composite resin or glass ionomer spheres attached to the edentulous mucosa have been used as references during edentulous arch scanning.[3,10,37,38] Alternatively, custom-made or prefabricated stainlesssteel, alumina, and other non-metallic materials have also been used.[15,36,39,40,47] In general, the presence of these markers slightly improves the overall accuracy of digital scans, particularly for precision.[10,38–40] In completely edentulous arches, Tao et al. found a significant improvement in precision of digital scans when markers were used only in the maxillary arch.[10] Interestingly, the mandibular scans had worse precision when the markers were added.[10] The impact of markers on the accuracy of edentulous arch digital scans might be specific to the IOS used as demonstrated by Rutkūnas et al.[38] Although the addition of markers improved the trueness of edentulous arch scans compared to the unaltered arches in the present study, the improvement was not significant and may not justify the additional clinical steps involved. However, these markers can also serve as fiducial markers during computedtomography (CT) scanning to merge digital scans with CT scans for dental implant planning and scan superimposition for restorative purposes.[48,49]

IOSs are sensitive to the translucency and glossiness of the object being scanned.[41,42,50] Accordingly, the opacification of the scanned surface by the application of scanning powder or spray may be beneficial.[43,50] This provides uniform reflectivity and reduces potential scanning errors.[41,43,51] Higher precision and reduced scanning time have been reported with the use of sprays and powders.[43] However, there is limited information available regarding the use of scanning spray with edentulous arches.[15] The use of scanning spray resulted in the highest trueness with the TRIOS 4 scanner but the lowest with Emerald S. The Emerald S scanner resulted in greater variability and some outliers with the scanning spray particularly in the maxillary arch. No particular factor could be identified for this observation. However, both scanners use different working principles, light sources, and imaging types which may contribute to this variability.[32] No other studies evaluating the effects of scanning sprays and powders on the accuracy of completely edentulous arches were available and therefore, no further comparisons could be made. The application of scanning sprays itself may introduce variability as different sprays have different layer thicknesses.[41] In addition, operators inexperienced in the use of scanning sprays often provide thicker and less uniform coatings which may influence the accuracy of the scans.[51] In this study, one type of scanning spray was applied by a single experienced operator to standardize the procedure. Scanning sprays and powders may pose an inhalation risk which may lead to inflammation of the bronchial system.[50] Proper protective measures and high-volume evacuation should be used.[50]

The application of PIP on the surface of edentulous arches has been described as a simple and inexpensive method to improve the accuracy of edentulous arch scans.[15,36,44] The PIP can be used alone or in conjunction with zinc oxide-eugenol cement.[15,36,44] Irregular shapes can be drawn on the surface of dry mucosa with a brush in order to create distinguishable features that improve image stitching.[44] Although this method may not provide much benefit and some difficulties might be experienced, the information available on this method is based on case reports and a single in vitro study.[15,36,37,44] PIP markings did not improve the scan accuracy in this study. With the TRIOS 4 scanner, adding PIP marks resulted in the lowest trueness but highest precision. Whereas, PIP marks with Emerald S scanner showed a less remarkable effect. It can be speculated that given the greater trueness of the TRIOS 4 scanner, it was able to detect the changes in surface topography related to the PIP application better than the Emerald S scanner. Therefore, the impact of PIP application was more obvious with the TRIOS 4 scanner.

Recently, a liquid-type scanningaid material has been introduced which has demonstrated in vitro improved scan accuracy and shorter scanning time compared to powder-type materials when scanning single teeth and short-span fixed dental prostheses.[42] However, for complete arch scans the liquid-type and powder-type materials performed similarly.[43] The use of liquid-type scanning aid material with completely edentulous arches has not been previously investigated. In this study, liquid-type scanning aid improved the trueness of edentulous arch scans for both scanners. However, the improvement was not statistically significant. It also improved precision but only for the TRIOS 4 scanner.

The second null hypothesis was also rejected as the conventional impressions had lower trueness than the TRIOS 4 scanner ($p = 0.001$) and lower precision than both TRIOS 4 ($p = 0.002$) and Emerald S ($p = 0.002$) scanners. Overall, digital scans were more accurate than conventional impressions. The TRIOS 4 scanner had better precision and trueness while the Emerald S only had better precision and comparable trueness to conventional impressions. Although the two-step final impression procedure continues to be the standard, many clinicians use a single irreversible hydrocolloid impression for complete denture fabrication.[3,6] The irreversible hydrocolloid impression in a stock tray is thought to yield the lowest accuracy and was used in this study as a negative control. While the PVS impression in a custom tray is thought to yield the most accurate results and was used as a positive control. These conventional groups were added for their outcomes to highlight where the deviations in digital scans stand within the scale of impression techniques available and have been used for decades. In this study irreversible hydrocolloid and PVS impressions were comparable; however, these results may not truly validate the simplified protocol for complete denture fabrication as the impression borders were not included.[6,7] Greater border variations have been reported with irreversible hydrocolloids which may compromise the results and necessitate multiple adjustments.[3]

The variation seen in this study may be of limited clinical value as the deviation values reported fell below the clinical threshold of 300 μm described by Osnes et al. and based on the deviation values of conventionally flasked dentures.[28] This is in line with previous studies and reports that could not identify significant or clinically discernable differences in accuracy when surface modifications of completely edentulous arches were carried out.[15,36] The in vitro nature of this study leads to some limitations. The compressibility of the model tissues is different from actual intraoral tissues which may result in higher variation between conventional impressions and digital scans.[11] The translucency of the artificial mucosa differs from natural mucosa which may also impact the accuracy of digital scans. Other variables not considered in this study such as scanning time and number of images may be affected by the use of scanning aids.[10,42,43] Furthermore, factors such as scanning strategy, operator experience, ambient lighting, and moisture that may influence scan accuracy and interact with scanning aids were not considered.[26,31] Dynamic border tissues that are difficult to scan were also not considered in this study.[3] Higher variability in border tissues and the inability to capture the functional borders are still a limitation of digital scans of completely edentulous arches.[3,11,15,23] Recapturing the borders conventionally during clinical evaluation of the denture may be required with the use of digital scans.[15,33] Finally, only two IOS systems and 4 scanningaids were considered. Additional investigations and clinical research are needed to further understand the impact of scanningaids on the accuracy of completely edentulous arch scans.

CONCLUSIONS

Within the limitations of this study the following conclusions can be drawn.

The arch being scanned had a significant effect on the accuracy of digital scans of completely edentulous arches, with the maxillary arch showing better overall accuracy compared to the mandibular arch. However, the difference was small and may be clinically negligible.

The type of scanner had a significant effect on the accuracy of digital scans of completely edentulous arches, with TRIOS 4 outperforming the Emerald S scanner and conventional methods.

The scanningaid had a significant effect on the trueness of digital scans of completely edentulous arches with a significant interaction between scanner and scanningaid.

The scanning spray and liquid-type scanningaid had the best trueness for the TRIOS 4 scanner, which was statistically better than PIP. The liquid-type scanningaid and composite markers improved the trueness of the Emerald S scanner but were not statistically better than other scanning aids.

TRIOS 4 had statistically better trueness than Emerald S with all scanning aids except PIP.

The liquid-type scanningaid can be recommended for both scanners to improve digital scan trueness for completely edentulous arches. The scanning spray can also be recommended with TRIOS 4 scanner only. Nevertheless, these improvements are small and may be of limited clinical impact.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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