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RESEARCH AND EDUCATION

Evaluation and comparison of the accuracy of three intraoral scanners for replicating a complete denture

Louise Le Texier, PhD,^a Emmanuel Nicolas, MD, PhD, HDR,^b and Cindy Batisse, MD, PhD^c

Entry into the digital workflow begins with the acquisition of physical data, which is then transformed into digital data enabling the computer aided design and manufacturing (CAD-CAM) of a prosthesis. Today, this acquisition can be carried out either at a prosthetics laboratory by digitizing conventional impressions using a desktop scanner (DS) (indirect CAD-CAM) or at the dental clinic by using an intraoral scanner (IOS). Until recently, the use of IOSs was limited to short-span fixed prosthetic restorations. Today, thanks to technological advances, IOSs are being increasingly used in digital acquisition for fixed prosthetics,¹ implant-supported prosthetics,² and orthodontics.³ Additionally, some systems are able to digitize a removable complete denture (RCD) or acquire images of edentulous ridges. Indeed, manufacturers are looking to expand the potential applications of IOSs, particularly in removable prosthodontics.

According to the International Organization for Standardization (ISO) standard 5725-1, accuracy is a general term that refers to both the trueness and precision of a

ABSTRACT

Statement of problem. Technological advances in digital acquisition tools have increased the scope of intraoral scanners (IOSs), including scanning a removable complete denture (RCD) to replicate it. However, studies assessing the accuracy of IOSs for replicating a maxillary or mandibular RCD are lacking.

Purpose. The purpose of this in vitro study was to evaluate the accuracy (trueness and precision) of 3 IOSs while replicating a maxillary and mandibular RCD.

Material and methods. One maxillary and 1 mandibular RCD were scanned with a desktop scanner (D2000) to obtain the reference model. Two operators scanned each RCD 5 times with 3 different IOSs (TRIOS 4, Primescan, and IS3800), following a predefined acquisition protocol. The 60 study models obtained were compared with the reference model using the Geomagic software program. For each comparison, the mean and standard deviation of discrepancy were calculated. Distances were measured on both the reference and the study model, and differences were calculated to assess whether sagittal or transverse deformations were present. The tolerance percentage of the volume of the digital model compared with the volume of the reference model was determined (difference tolerance was set at 0.1 mm). A univariate analysis of variance followed by a post hoc analysis using the Student-Newman-Keuls ($\alpha=.05$) test was performed to determine the truest and the most precise IOS.

Results. The TRIOS 4 and Primescan IOSs had comparable trueness, with mean dimensional variations of $47 \pm 27 \mu\text{m}$ and $57 \pm 8 \mu\text{m}$ respectively compared with the reference model. The IS3800 had a lower trueness ($98 \pm 35 \mu\text{m}$). Primescan was significantly more precise with a mean standard deviation of $64 \pm 15 \mu\text{m}$ ($P<.05$). The TRIOS 4 ($141 \pm 48 \mu\text{m}$) and IS3800 ($129 \pm 24 \mu\text{m}$) had comparable precision. Primescan showed the least sagittal and transverse deformation.

Conclusions. This study determined that an RCD can be replicated using an IOS, although all IOSs did not have equal accuracy. An in vivo study needs to assess whether this procedure is clinically acceptable. (J Prosthet Dent xxxx;xxx:xxx-xxx)

method.⁴ Trueness is the closeness of agreement between the arithmetic mean of many test results and the true reference value and is measured with the average of the dimensional variations resulting from the test results. Precision is the closeness of agreement between test results and is calculated from the standard deviations of test results.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Clinical Implications

This *in vitro* study validated the use of IOSs to replicate an RCD. The digital acquisition of RCDs could facilitate different clinical situations. Keeping an impression file of a new RCD would allow its quick duplication and replacement in case of loss or damage. When treating elderly patients, the RCD could be scanned with an IOS, and the file sent to the dental laboratory technician without depriving the patient of the prosthesis.

The accuracy of IOSs is influenced by factors that include the acquisition strategy defined,⁵⁻⁷ the acquisition environment,⁸ the type of prosthesis scanned (maxillary or mandibular),⁹ the software program version,^{10,11} the technology of IOSs used,¹²⁻¹⁴ the distance between the IOS tip and the area to be scanned,¹⁵ and the size of the IOS tip.^{16,17} IOSs have been reported to have similar or even better accuracy than conventional impressions for a prepared single tooth,^{18,19} a completely dentate arch,²⁰ or for implant recording.²¹ Studies also showed different accuracy between IOSs when acquiring a completely dentate,^{18,22} partially dentate, or edentulous arch.²³ Nevertheless, the feasibility and accuracy of IOSs for the replication of an RCD has only been assessed in clinical reports.^{24,25}

Acquiring an existing RCD with an IOS could have several advantages and clinical applications. The production of an RCD requires numerous sessions, which can be tedious for both the patient and the dentist. Scanning an RCD would enable to produce a denture duplicate in case of loss or damage. Therefore, with the digital workflow, a new RCD identical to the initial RCD could be designed. In addition, if a patient has well-integrated existing RCDs, it may be possible to refit these prostheses to make the new RCDs. In this situation, the rehabilitated RCDs are usually sent to a prosthetic laboratory to be scanned using a DS, depriving the patient of the prostheses. Using an IOS would avoid this step, improving patient comfort. Finally, a digital file of a typical RCD could be coupled to a cone beam computed tomography (CBCT) scan to help plan the treatment of implant-supported prostheses.

This *in vitro* study was carried out to assess the accuracy of three IOSs in replicating an RCD. The null hypothesis was that no difference in accuracy would be found among the different IOSs.

MATERIAL AND METHODS

A maxillary (Mx) and a mandibular (Mb) RCD meeting the Class I criteria of the McGarry classification²⁶ were chosen as models. Ethical approval had been obtained to use human-derived specimens. Each RCD was scanned

using a DS (D2000; 3Shape A/S) at a 5-megapixel resolution to obtain a digital reference model. The 2 files were exported in standard tessellation language (STL) format as the digital model reference files.

Two operators (C.B., L.L.T.) scanned each RCD 5 times with 3 IOSs (TRIOS 4 v21.2.2.; 3Shape A/S, Primescan v5.1.3.; Dentsply Sirona, and IS3800 v1.0.4.; Dexis). Acquisition sessions were spaced at least half a day apart to ensure optimum operator concentration (1 session corresponded to 1 type of RCD scanned 5 times by an IOS). Before each data acquisition, The Primescan and TRIOS IOSs were calibrated according to the supplier's protocol. The IS3800's supplier did not specify calibration. Acquisitions were carried out at a dentist's office under natural light to reflect practice conditions. During acquisition, the prosthesis was handheld by the operator who, began with a scan of the external surfaces of the RCD and then the borders and intaglio surfaces (Fig. 1). The prosthesis was not powdered. The scans were exported in STL format.

Each obtained file was compared with the reference file by using an engineering software program (Geomagic Control X v2023.0.0.; 3D Systems), and the mean and standard deviation of discrepancy between the reference model and the digital model were calculated. The percentage of similarity between the volume of the digital model and the volume of the reference model with a difference tolerance set at 100 μm was determined with the software program. A qualitative and quantitative visual analysis was also carried out by using a colorimetric scale to observe positive and negative dimensional variations, with a tolerance set at 100 μm .^{16,27} To assess any deformations created during RCD acquisition, anatomic points were manually positioned by the same operator in the mesial fossae of the maxillary first molars and mandibular right (FMR) and left (FML) second molars and at the level of the incisal guide angle (IGA). Three distances were measured with the Geomagic software program: d1: FML-IGA, d2: FMR-IGA, and d3: FML-FMR, as well as the angle α formed between d1 and d2 (Fig. 2). Differences in absolute values between the distance and angle values measured on the reference model and the digital model were calculated in a spreadsheet (Excel; Microsoft Corp) and noted as $\Delta d1$, $\Delta d2$, $\Delta d3$, and $\Delta \alpha$. The mean and standard deviation for each IOS for Mx and Mb RCD were also calculated. Distances d1 and d2 assessed anteroposterior deformations. Distance d3 and the angle α assessed transverse deformations.

Statistical analysis was performed with a statistical software program (IBM SPSS Statistics, v29; IBM Corp). Interoperator variability was tested using a Student *t* test on the mean of discrepancy, the standard deviation, and the percentage tolerance obtained by using the Geomagic software program. A univariate analysis of

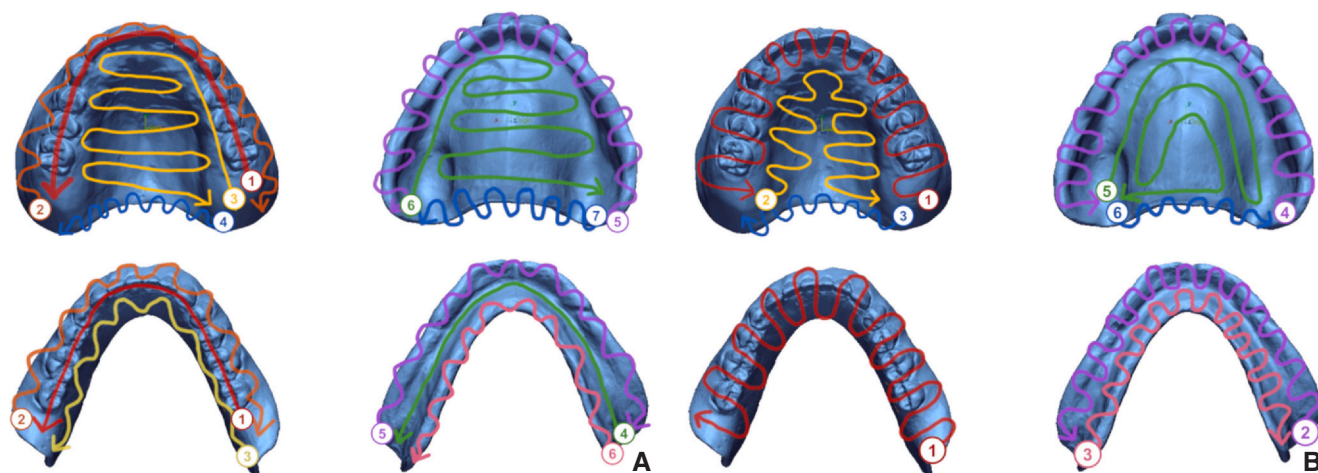


Figure 1. Scan strategies used for maxillary and mandibular complete dentures. A, Primescan and IS3800. B, TRIOS.

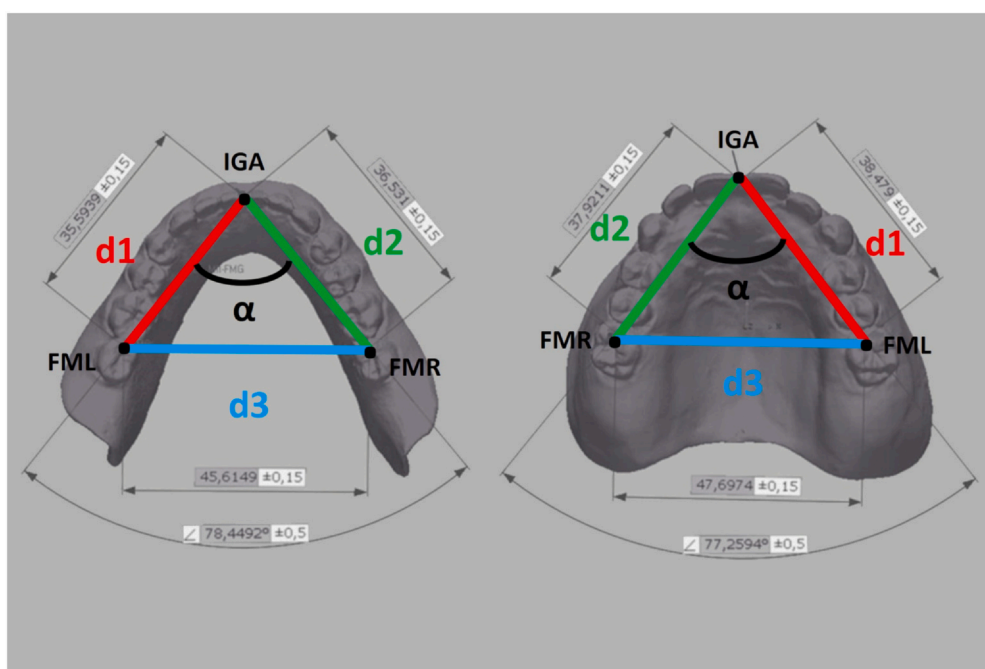


Figure 2. Screenshot of Geomagic software program showing measured data (d1, d2, d3, and angle α) for complete dentures: maxillary (right) and mandibular (left).

variance followed by a post hoc analysis using the Student-Newman-Keuls test ($\alpha=0.05$) was performed to determine the most true and precise IOS. Trueness was assessed from the mean of the discrepancy. A mean of the discrepancy of each measured model was obtained for each IOS globally and as a function of location. Precision was assessed from the standard deviation of discrepancy. The mean of the standard deviations of the discrepancy of each model measured and the standard deviation of this mean are calculated for each IOS globally and as a function of location. Sagittal and/or transverse deformations of the measured models were

highlighted by calculating the difference between the reference distances and the measured distances ($\Delta d1$, $\Delta d2$, $\Delta d3$, and $\Delta \alpha$).

RESULTS

For each RCD, 30 pairwise comparisons (measured file versus reference file) were carried out. Discrepancies between the 2 operators' acquisitions for each IOS were not statistically different ($P>0.05$), showing no significant interoperator variability. Therefore, the results for both operators were combined.

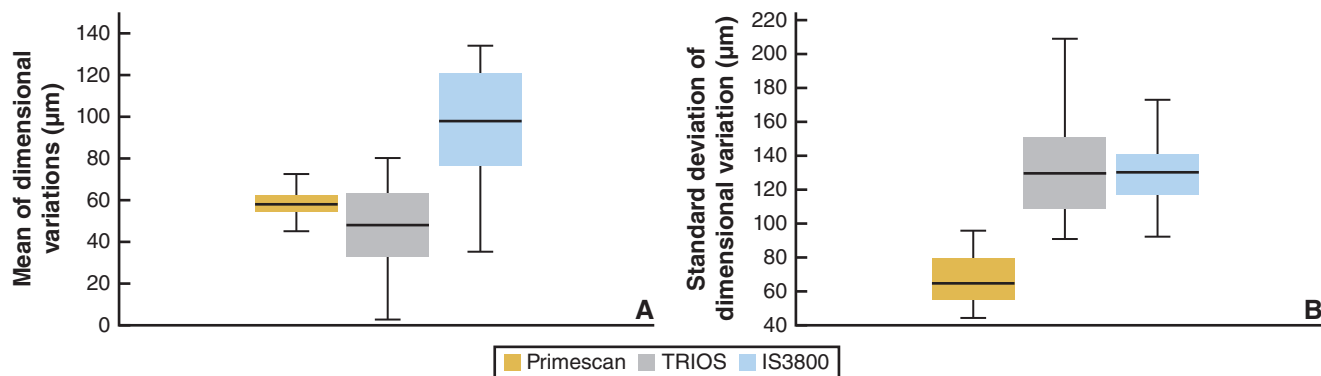


Figure 3. Results for each intraoral scanner for both complete dentures. A, Trueness. B, Precision.

For trueness assessment with the ISO 5725–1 standard, irrespective of the type of prosthesis (Mx or Mb), the TRIOS and Primescan scanners had statistically similar results ($P > .05$), with a mean discrepancy of $47 \pm 27 \mu\text{m}$ and $57 \pm 8 \mu\text{m}$ respectively compared with the reference model. The IS3800 scanner had significantly lower trueness, $98 \pm 37 \mu\text{m}$ ($P < .05$) (Fig. 3A). Similar trueness results were found when acquisitions were compared only for the Mx RCD (Table 1). For the mandible, the trueness of the three IOSs were significantly different ($P < .05$).

For precision assessment using the ISO 5725–1 standard, irrespective of the type of prosthesis, the Primescan was significantly the most precise IOS, with a mean standard deviation of $64 \pm 15 \mu\text{m}$ ($P < .05$). The TRIOS and IS3800 scanners had lower values but had a comparable precision, with $141 \pm 48 \mu\text{m}$ and $129 \pm 24 \mu\text{m}$ respectively ($P > .05$) (Fig. 3B). Similar precision results were obtained when acquisitions were compared only for maxillary or mandibular RCD (Table 1).

The clinical assessment of accuracy was based on the percentage tolerance, the colorimetric analysis, and the assessment of model deformation by using measured distances. For both RCDs, the three IOSs studied were significantly different in terms of percentage tolerance ($P < .05$). The Primescan showed the best results for both RCDs, followed by the TRIOS and the IS3800. The Primescan showed better results for Mx RCD than Mb RCD at 84% and 69% respectively. Conversely, the TRIOS and IS3800 scanners had better results for Mb

RCD (56% and 48% respectively) than for Mx RCD (52% and 42%).

The visual analysis confirmed these results. The Primescan was the most accurate IOS for both the maxilla and mandible (Fig. 4). In the maxilla, most of discrepancies observed in the Primescan were of the order of 0.1 mm (light yellow in color). They occurred mainly on the buccal surfaces of the teeth and on the anterior crest on the intaglio surface (Fig. 5A). In the TRIOS and IS3800 scanners, the discrepancies observed may have involved clinically relevant areas (lateral or posterior border of the denture or the teeth's occlusal surfaces) that could make the RCD unstable (Fig. 5A). For all 30 maxillary scans, a greater discrepancy (greater than 0.5 mm) was found in the medial zone of the posterior part of the Mx RCD cameo surface (Fig. 5A). In the mandible, the greatest discrepancies in the Primescan were found in the intaglio surface of the RCD. On the cameo surface, variations were localized at tooth level (Fig. 5B). The TRIOS created the greatest discrepancies, from 0.6 to -0.2 mm (dark blue to light yellow). The retromolar trigones were the most affected areas, both on the intaglio and cameo surface (Fig. 5B). For the 30 acquisitions made on the mandible, discrepancies were observed at the posterior border of the cameo surface, especially lingually (Fig. 5B).

Maxillary and mandibular results were analyzed separately because of a reversed acquisition pattern between Mx and Mb RCD. Tables 2 and 3 summarize the mean differences between values from the reference

Table 1. Trueness and precision of IOSs for maxillary and mandibular complete dentures (μm) (mean \pm standard deviation)

IOSs	TRUENESS					PRECISION			
	Maxilla		Mandible			Maxilla		Mandible	
	1	2	1	2	3	1	2	1	2
PS	58 \pm 9			56 \pm 7		52 \pm 6		77 \pm 9	
TS	59 \pm 26		34 \pm 21				142 \pm 62		139 \pm 32
IS		106 \pm 47			90 \pm 24		119 \pm 24		140 \pm 21
P	.909	>.999	>.999	>.999	>.999	>.999	.179	>.999	.928

IOSs, intraoral scanners; IS, IS3800; PS, Primescan; TS, TRIOS 4. Significance ($P < .05$).

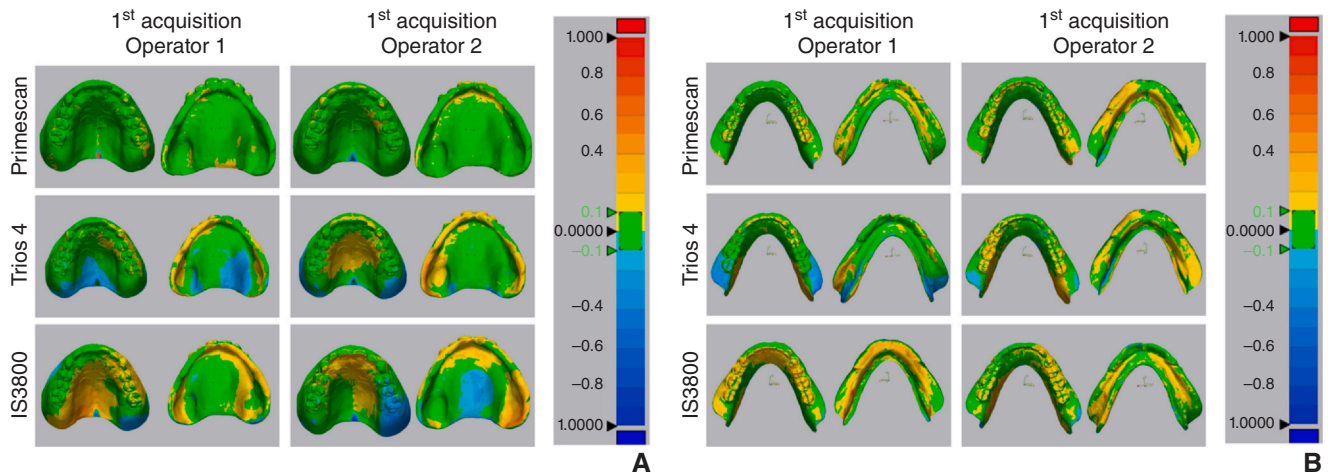


Figure 4. Comparisons using colorimetric scale (mm) of dimensional variations between digital reference maxilla model and studied models obtained during first acquisition of each operator for each intraoral scanner. A, Maxillary. B, Mandibular. Color deviations range from -1 mm (blue) to +1 mm (red).

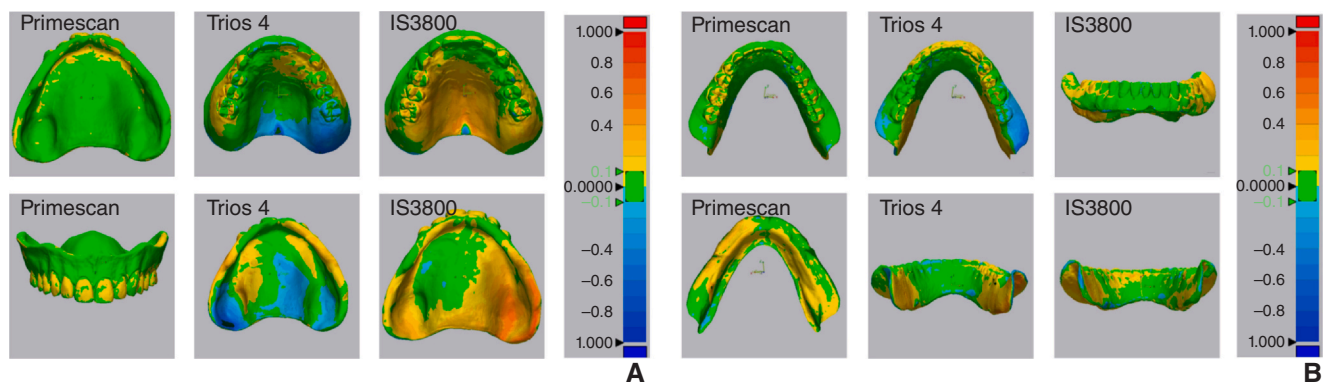


Figure 5. Representative examples of comparisons using a colorimetric scale (mm) of dimensional variations between digital reference model and digital models studied. A, Maxillary complete denture. B, Mandibular complete denture. Color deviations range from -1 mm (blue) to +1 mm (red).

Table 2. Means \pm standard deviations absolute values (μm for $\Delta d1$, $\Delta d2$, $\Delta d3$; degree for $\Delta\alpha$) for each intraoral scanner for maxillary complete denture (left) and statistical significance (right) ($P < .05$)

IOSs	$\Delta d1$	$\Delta d2$	$\Delta d3$	$\Delta\alpha$	$\Delta d1$	$\Delta d2$	$\Delta d3$	$\Delta\alpha$
PS	5 \pm 14	2 \pm 20	0.6 \pm 12	0.002 \pm 0.029				
TS	38 \pm 54	110 \pm 53	72 \pm 27	0.042 \pm 0.12				
IS	38 \pm 60	27 \pm 54	11 \pm 25	0.1 \pm 0.101				

Black solid line represents statistical significances among scanners. IS, IS3800; PS, Primescan; TS, TRIOS 4.

Table 3. Means \pm standard deviations absolute values (μm for $\Delta d1$, $\Delta d2$, $\Delta d3$; degree for $\Delta\alpha$) for each intraoral scanner for mandibular complete denture (left) and statistical significance (right) ($P < .05$)

IOSs	$\Delta d1$	$\Delta d2$	$\Delta d3$	$\Delta\alpha$	$\Delta d1$	$\Delta d2$	$\Delta d3$	$\Delta\alpha$
PS	4 \pm 8	14 \pm 20	5 \pm 30	0.023 \pm 0.067				
TS	3 \pm 44	29 \pm 52	15 \pm 117	0.073 \pm 0.162				
IS	57 \pm 61	97 \pm 111	151 \pm 110	0.11 \pm 0.231				

Black solid line represents statistical significances among scanners. IS, IS3800; PS, Primescan; TS, TRIOS 4.

model and those from the digital model for each IOS for both Mx and Mb RCD. The Primescan was the IOS that caused the least deformation in the anteroposterior and in the transverse axis in the Mx and Mb.

With the Primescan, deformations along the anteroposterior and transverse axes were all less than 14 μm , and $\Delta\alpha$ was less than 0.03 degrees. For the Mb RCD, the TRIOS showed statistically comparable results with those of the

Primescan. The IS3800 was the IOS that caused the most deformations in the anteroposterior and transverse axes, with variations above 150 μm .

DISCUSSION

The null hypothesis that no difference in accuracy would be found among the different IOSs was rejected in the duplication of an RCD. The Primescan was significantly the most precise IOS, the truest (or comparable with the TRIOS), with the least dimensional distortions in duplicating an RCD.

This study demonstrated the feasibility of using an IOS to scan RCD by proposing an acquisition protocol adapted to conditions in a dental practice. First, the RCD was able to be replicated in a single step acquisition, as opposed to the 3-step acquisitions (cameo and intaglio surfaces and finally the prosthesis margin) previously described.²⁴ The digital file created must then be transferred to a CAD software program to smooth out areas of overlap or irregularity between the intaglio and cameo surfaces, particularly, to smooth out the borders of the prosthesis. This acquisition protocol had several drawbacks. It generated an approximation at the borders of the prosthesis, which may reduce the retention of the future prosthesis and necessitate relining. The scanning also requires extra modeling to produce the RCD. Since a 1-step acquisition protocol is feasible with the IOS, it should be a preferred alternative to the 3-step protocol, being more accurate and less time consuming. In addition, the accuracy of IOSs has been reported to vary according to the acquisition strategy defined.⁵⁻⁷ In the present study, the acquisition paths were defined according to the supplier data. A different acquisition protocol was therefore used for Mx and Mb RCDs because the type of the prosthesis has been reported to impact the acquisition path.⁹ Furthermore, the reproducibility of the scan paths may differ slightly from one acquisition to the next, as this could also happen in clinical practice. Other factors can also influence the accuracy of IOSs according to the ISO 5725-1 standard,⁴ including the operator, the equipment used, the calibration of the measuring tool, the environment, and the elapsed time between each measurement. Particular attention was paid to these factors to reduce variability. The difference in the operator's experience in using IOSs did not impact the results. IOS versions with similar release dates were used. The Primescan and TRIOS were calibrated before each acquisition session to reduce the risk of data distortion.¹² The software program version of each IOS was not upgraded, since it has been reported to have a great impact on IOS accuracy.^{10,11} With regard to the acquisition environment, Revilla-Léon et al⁸ reported that dental chair lighting or natural light did not give the best accuracy results. However, in the present

study, the acquisition conditions were designed to be as close as possible to clinical conditions, with duplication of the RCD being simulated at the dental chair. The accuracy results from the 3 tested IOSs showed an RCD can be replicated under natural light. Finally, this study did not consider the average time required to digitize an RCD. This could be tested in future studies.

The authors are unaware of a previous study that investigated the accuracy of different IOSs for duplicating an RCD. Other studies on the accuracy of IOSs for different clinical purposes^{18,23} reported similar results. Schlenz and al²² compared the accuracy of 5 IOSs (including Primescan, TRIOS 4, and IS3800) for scanning completely dentate arches, reporting that IS 3800 was the least accurate IOS, consistent with the present study. Kaya and Bilmenoglu² compared the accuracy of fourteen IOSs for an all-on-4 scan and reported that the Primescan had statistically the best precision (12 \pm 3 μm). The TRIOS was in third place with a precision of 42 \pm 17 μm , just after Itero5D. Considering the difficulty of acquiring an RCD (cameo and intaglio surfaces), these results were consistent with those obtained for the Mx RCD scan. Differences in accuracy may be explained by the technology used, specific to each IOS,^{13,14} the distance between the IOS tip and the area to be scanned,¹⁵ and the size of the IOS tip.

All the referenced studies testing the accuracy of an IOS followed the ISO 5725-1 standard,⁴ which describes how to assess accuracy but does not define the trueness and precision thresholds for an instrument's accuracy. In dentistry, results allow conclusions to be drawn about the accuracy of IOSs based on trueness and precision values. However, these values have not been linked to a threshold of clinical acceptability. Thus, the clinical impact of IOS accuracy is subject to individual interpretation. In this study, variables such as percentage tolerance and dimensional variations were calculated using distance and angle measurements to complement the ISO standard variables for a more clinical approach. Measuring distances and angles made it possible to assess differences in deformations in the anteroposterior and transverse axis between the digital and the reference model. The average sagittal and transverse deformations of the Primescan was less than 10 μm . Also, the maximum recorded deformation obtained with the IS3800 was 151 μm for $\Delta\text{d}3$. These values can be compared with known clinical data such as active tactile sensitivity, the proprioceptive information enabling interocclusal thickness to be perceived during mastication. The threshold of active tactile sensitivity (36 to 92 μm) was reported to be much higher in edentulous patients rehabilitated with an RCD than in dentate patients or those rehabilitated with implants.^{28,29} The higher threshold reported to be associated with the loss of periodontal receptors and the absence of osteoperception.^{28,29} Thus, the dimensional

variations observed with the Primescan seemed clinically acceptable. For other IOSs, deformation values remained below 100 μm , which also seemed acceptable. In clinical practice, 80 to 200- μm articulating paper is typically used for occlusal evaluation in removable prosthetics.^{30,31} Nevertheless, greater inaccuracy may increase the risk of injury during RCD insertion, which may increase the number of adjustment visits, require longer adaptation time to a new RCD,³² and/or lead to difficulties in wearing the denture.³³

The tolerance percentage was also calculated and combined with the colorimetric scale. The percentage tolerance, like most quantitative analysis, is based on averages over the entire RCD volume. However, from a clinical point of view, certain areas such as the occlusal surfaces, the prosthesis margins, and the RCD intaglio surface have greater clinical importance than the rest of the prosthesis. The Primescan had the best percentage tolerance in the Mx (84%) and Mb (69%), and the dimensional variations observed for the Primescan were in areas of low impact in terms of integration and clinical adaptation of the future RCD. Quantitative analysis showed that the TRIOS was comparable in trueness with the Primescan in the Mx and better than the Primescan in the Mb. However, some discrepancies observed for the TRIOS were concentrated in areas of high clinical interest in the Mx and Mb. If most discrepancies were concentrated on a small proportion of the denture's total volume, clinical repercussions would be more likely to occur. Finally, greater dimensional variation was observed in the medial zone of the posterior part of the Mx RCD cameo surface and in the posterior border of the mandibular RCD cameo surface, especially at the lingual surface, regardless of the IOS. These are the areas where IOSs had the most difficulties when duplicating an RCD by using acquisition paths. Gómez-Polo et al⁹ used other acquisition paths which did not highlight the same areas. However, these areas do not have a strong clinical impact on RCD adaptation and do not question the acquisition protocol and the use of IOSs to duplicate an RCD. Clinically, these discrepancies may cause occlusal imbalance and failure to adapt the bases to the prosthetic bearing surfaces and to the movement of the paraprosthesis organs, leading to a loss of retention and stabilization of the RCD, injury, and/or difficulty in integrating the prostheses.

Limitations of the present study included the in vitro design. An in vivo study would assess the acceptance and integration of RCD and confirm the use of IOSs to duplicate an RCD. Also, the current study assessed the feasibility of duplicating one type of Mx and Md RCD with three IOSs systems. Additional laboratory studies are recommended to further evaluate whether RCDs with different anatomy or other scanning systems would influence RCD duplication.

CONCLUSIONS

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

1. The type of IOS had a significant effect on the trueness and precision of the RCD digital scans.
2. The Primescan was the most accurate IOS for duplicating maxillary and mandibular removable complete dentures.

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