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In vitro and in vivo accuracy of full-arch digital implant impressions

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Abstract

Objectives: The main objective of the study was to compare the accuracy of full-arch digital implant impressions for fixed dental prosthesis under in vitro and in vivo conditions.

Materials and Methods: Eight patients (five women and three men) with at least one edentulous arch and with 4–6 osseointegrated implants participated in this study. For each edentulous arch (n = 10), experimental screw-retained titanium bar with attached four scan bodies was fabricated. The bar containing four scan bodies was screw-retained intraorally on implants and scanned with Trios 3 intraoral scanner eight times (IOS group, in vivo). Then, the bar was attached to the master cast and scanned eight times again with the same intraoral scanner (MIOS group, in vitro). Finally, the bar with scan bodies was scanned 8 times with a laboratory scanner (reference). Precision and trueness were calculated for 3 distances and 3 angles between the scan bodies (1–2, 1–3, and 1–4) in IOS and MIOS groups.

Results: Precision and trueness for the largest distance (1–4) were found to be 44 ± 18 μm and 32 ± 19 μm for the IOS group and 31 ± 16 μm and 30 ± 14 μm for MIOS group, respectively. Precision and trueness for the angle between the most distant scan bodies (1–4) were 0.22 ± 0.14° and 0.18 ± 0.10° for the IOS group and 0.16 ± 0.11° and 0.07 ± 0.05° for MIOS group, respectively.

Conclusions: Intraoral conditions moderately affected the precision and trueness of Trios 3 (3Shape) intraoral scanner. Results of in vitro accuracy studies cannot be directly transferred to the clinical field.

KEYWORDS
clinical assessment, diagnosis, patient centered outcomes, prosthodontics

1 | INTRODUCTION

Accuracy of dental implant impressions is directly associated with the accuracy and fit of the final implant-supported prosthesis (Lee et al., 2008; Papaspyridakos et al., 2014a). Misfitting prostheses may be related to the increased rate of biological and technical complications and affect the long-term success of dental implants and prosthetic reconstructions (Katsoulis et al., 2017).

Although conventional implant impressions have served as a standard method for a long time, this workflow has its limitations as it involves a considerable number of separate clinical and laboratory steps, and resulting accuracy dependent on the skills of operator, material, and technique selection (Heckmann et al., 2004). Digital impressions with an intraoral scanner (IOS) became a widely used procedure suitable for single or short-span tooth- and implant-supported fixed dental prostheses (Miyoshi et al., 2020) (Ahlholm et al., 2018). It is suggested that digital impressions could minimize human factor, increase patient comfort and efficiency of impression-taking procedures (Gjelvold et al., 2016) (Delize et al., 2019).

The accuracy of conventional and digital impressions is decreasing with increased numbers and angulations of the implants (Papaspyridakos et al., 2014b). One of the most challenging situations regarding implant impression accuracy remains to be full-arch situations (Papaspyridakos, Hirayama, et al., 2016).

An increasing amount of data on the accuracy of digital impressions for full-arch implant-supported fixed prostheses show promising results. Many studies have demonstrated mean errors of full-arch digital impressions being less than 100 μm (Gimenez-Gonzalez et al., 2016; Gintaute, 2015; Mangano et al., 2016; Papaspyridakos, Gallucci, et al., 2016; Vandeweghe et al., 2016) (Flügge et al., 2018). As the absolute majority of these findings are reported by in vitro studies, their clinical relevance should be taken with caution. Laboratory studies eliminate some of the clinical conditions such as intraoral humidity, patient movements, fogging of scanning device, limited mouth opening, tongue and soft tissue movements, and other factors that could compromise the accuracy (Rutkūnas et al., 2017). Due to these circumstances and minimal space to manipulate the tip of IOS, intraoral scanning is much more difficult to perform clinically. However, it is not known how intraoral conditions can alter the accuracy of digital impressions.

Very few clinical studies assessing the accuracy of IOS impressions are published. (Alsharbaty et al., 2018; Andriessen et al., 2014; Gedrimiene et al., 2019) Also, none of them have evaluated the full-arch digital impression accuracy under in vivo conditions.

In clinical studies, only a comparison between conventional and digital impressions is possible, as there is no reliable way to obtain the reference data. (Chochlidakis et al., 2020) (Cappare et al., 2019a) An alternative approach is to compare the accuracy of digital impressions performed under in vitro and in vivo conditions. It was shown that dental arch intraoral scanning was twice less precise than the extraoral scanning of the model of the same dental arch. (Flugge et al., 2013) Nevertheless, little is known on how in vivo conditions can affect the accuracy of a full-arch digital implant impression.

For this reason, a novel study protocol was implemented, allowing a direct comparison of full-arch digital implant impressions under in vitro and in vivo conditions. In this way, the effect of intraoral (in vivo) conditions on the accuracy of digital impressions could be estimated.

The study aimed to evaluate and compare full-arch digital impression accuracy if scanning is done intraorally (in vivo) and on the master cast (in vitro). The null hypothesis of this study was that no difference in the precision and the trueness of full-arch digital implant impressions exist between in vivo and in vitro impressions.

2 | MATERIALS AND METHODS

The study protocol was approved by the Vilnius Regional Ethics Committee for Biomedical Research (No 158 200–16–861–370). Eight participants (five women and three men) aged 57–70 years (mean age 64.3 ± 4.6 years) were involved in the study under the signed informed consent.

Patients with at least one edentulous arch and with 4–6 osseointegrated dental implants (BLT, Straumann AG) per arch have participated (n = 10 edentulous arches: 5 mandibular and 5 maxillary). For each case, a conventional open-tray polyvinyl-siloxane impression (Express, 3 M) was taken to fabricate a screw-retained titanium bar with four holes in the area of second incisors and second premolar teeth. The titanium bar was sandblasted to obtain a non-reflective surface. Four scan bodies (RC Mono Scanbody, Straumann AG) were attached to the bar with auto-polymerizing resin (Pattern-resin, GC Corporation) perpendicular to the top surface of the bar and parallel to each other.

The bar containing the scan bodies was screw-retained to the implants in the edentulous jaw, and the situation was scanned with IOS (Trios 3, 3Shape) eight times following the scanning strategy recommended by the manufacturer (IOS group). Then the bar was carefully removed from the mouth and screwed to the master cast and again scanned eight times by the same operator using the same scanning strategy (MIOS group) (Figure 1). All the files were inspected additionally for the absence of any scanning insufficiencies. Then, the master cast with titanium bar and scan bodies attached was scanned 8 times with a high-accuracy (4 μm according to ISO 12836) laboratory scanner (E4, 3Shape), considering this as the reference data (RS group). Thus, 24 scans were acquired per one edentulous arch, and in total, 240 scans were obtained from 10 edentulous arches.

Scans were exported in standard tessellation language (STL) file format. All scans were aligned, and the bar area was cut using the same cutting plane by Geomagic Control X 2018[1] (3D Systems Corporation) software, leaving only STL data containing the scan bodies. Figure 2 shows the data acquisition workflow. Surface alignment and measurements were performed using Geomagic Control X 2018 software.

In this study, three parameters were evaluated: the distance and angulation between the scan bodies and surface distance between aligned 3D images (superimposition of 3D images). Distance and angulation accuracy evaluation was based on calculating the mean values of the unsigned deviations. Surface distance between aligned 3D images was evaluated using RMS (root mean squared) values of the deviations.

The workflow of the data analysis is presented in Figure 3. Distance measurements were done between the center points determined on the upper surface of scan bodies. To select these points, the CAD files of scan bodies were superimposed on the scan surface using initial transform alignment followed by the precise alignment using the best-fit algorithm. The top plane center of the scan body

[1]https://www.3dsystems.com/software/geomagic-control-x

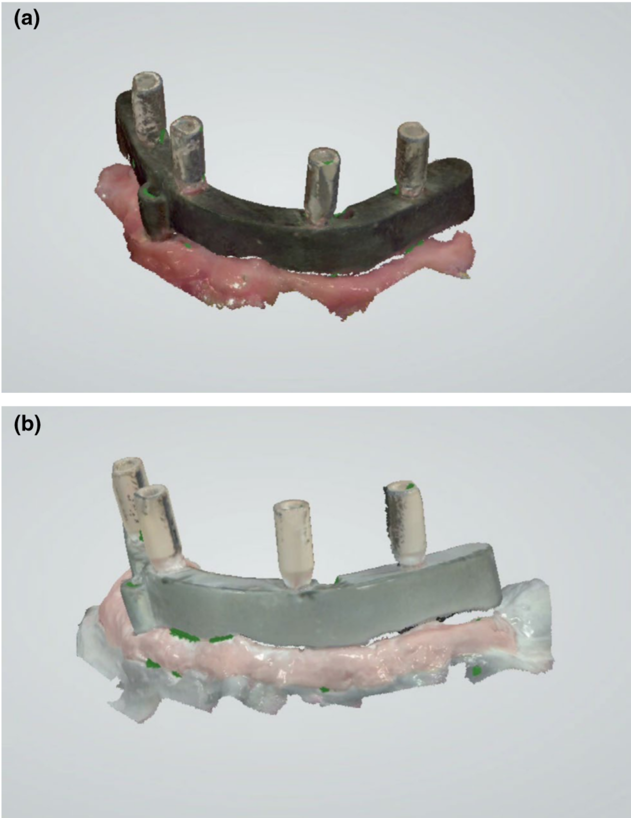

FIGURE 1 Same titanium bar with 4 scan bodies attached was scanned intraorally (a) under in vivo conditions and extraorally (b) under in vitro conditions using Trios 3 (3Shape, Copenhagen) intraoral scanner

The measurements of each distance obtained from eight scans of the case using selected scanning modality were compared with each other to evaluate the precision. For the evaluation of trueness, distance measurements obtained from RS were averaged for each distance of each case. The differences between measured distances in RS data and ones from MIOS and IOS data sets were calculated. These differences formed the final data array for the statistical analysis of trueness.

Angles between the axis of the reference and other scan bodies (Figure 5) were also evaluated and compared. Angles in 3D space (1–2, 1–3, and 1–4) were measured between the vectors extracted from aligned CAD files of scan bodies by using Geomagic Control X 2018 software. Further, workflow for precision and trueness evaluation of angulation was identical to the previously described one that was used for the distance assessments.

Scan surface accuracy was evaluated, calculating the intersurface distance between the scans using the 3D compare tool of the Geomagic Control X software. Initially, each of the surfaces under comparison was imported into the software, aligned using transform alignment with manually selected reference points, and in the next step, aligned precisely by applying the best-fit alignment procedure. Then the shortest 3D distance between surface points was calculated.

To evaluate the scanning precision of 3D surfaces in each group (RS, MIOS, or IOS), 8 scans of the same case were merged. From these 8 scans, one scan having the smallest average distance from the merged surface was selected (reference surface). As the next step, the rest of the seven surfaces were 3D compared with the

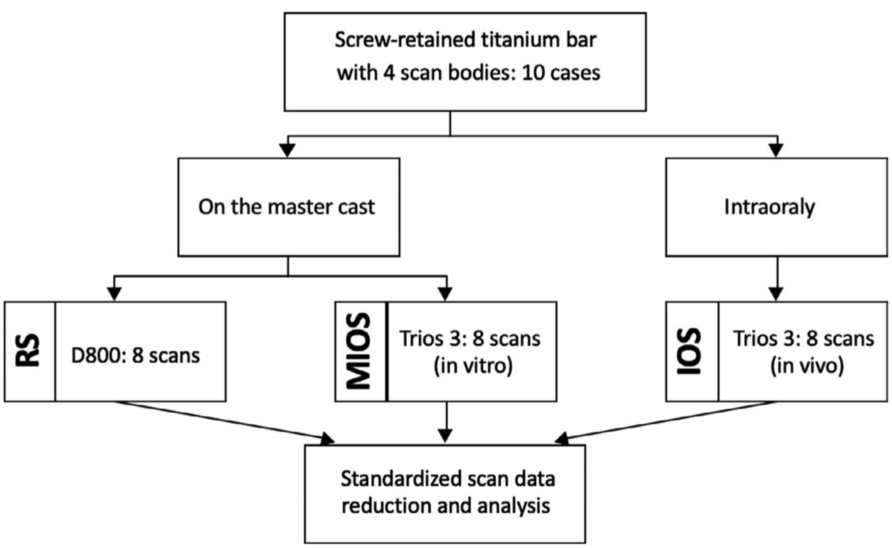

FIGURE 2 Data acquisition workflow

was identified using software tools. The three distances were measured between the scan bodies: 1–2, 1–3, and 1–4 (Figure 4). This comprised 72 measurements for each case (n = 8 repeated scans) with each scanning modality (IOS, MIOS, and RS). In total, 720 linear measurements were made.

reference surface, and resulting RMS values were exported for the precision analysis.

To assess the trueness, 8 scans from the RS group of each case were merged, and one scan having the smallest deviation from the merged surface was selected (reference surface). After this, the

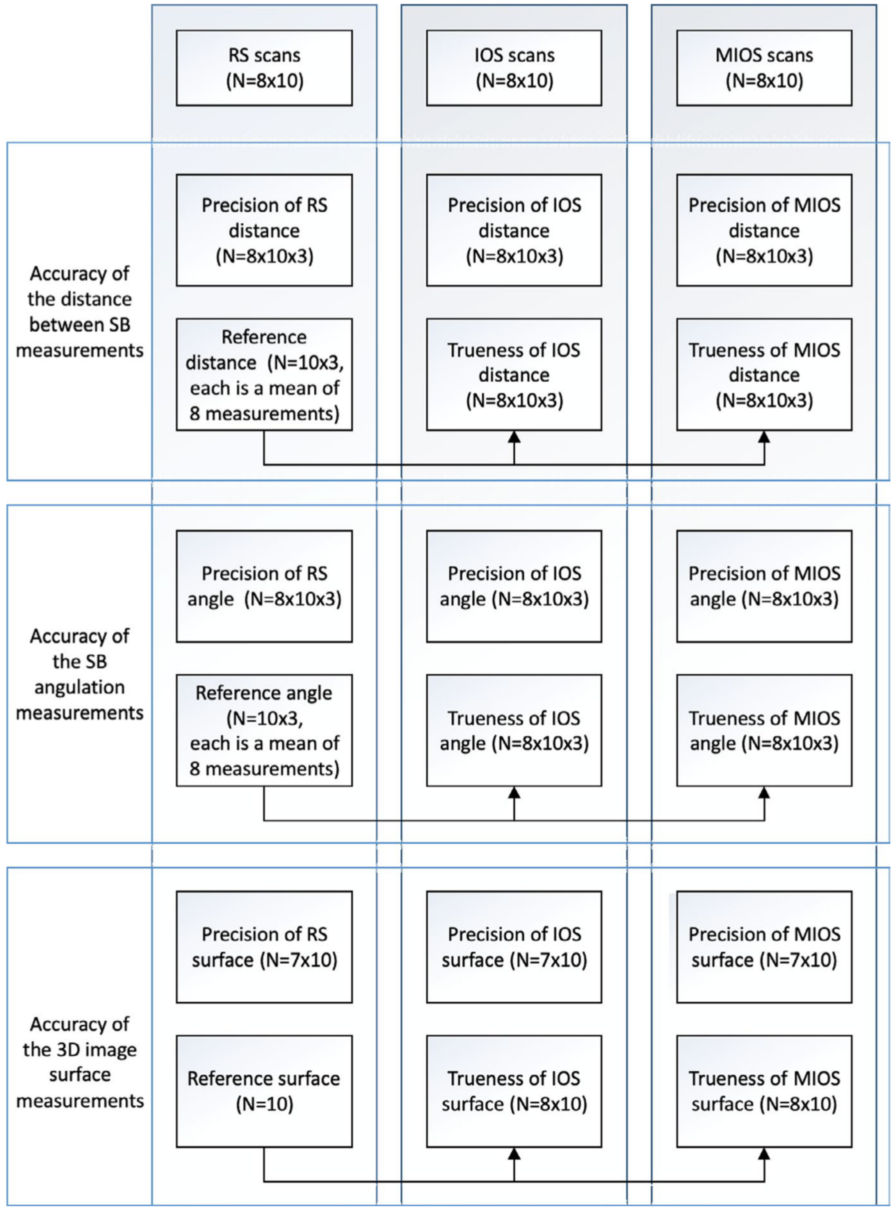

FIGURE 3 Data analysis workflow used to evaluate the accuracy of distance and angulation between the scan bodies and surface distance between aligned 3D images. N represents the number of images or measurements used in a certain step of the analysis

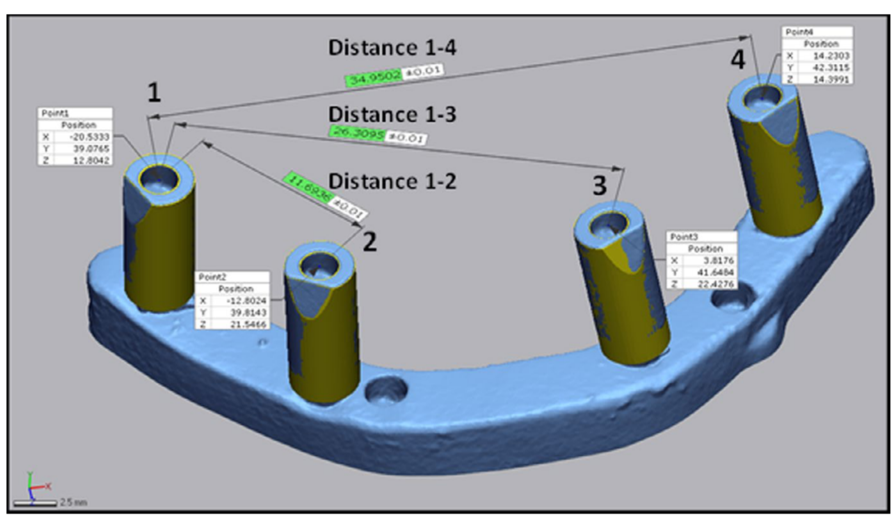

FIGURE 4 Distance measurement setup for intraoral and extraoral scanning comparison

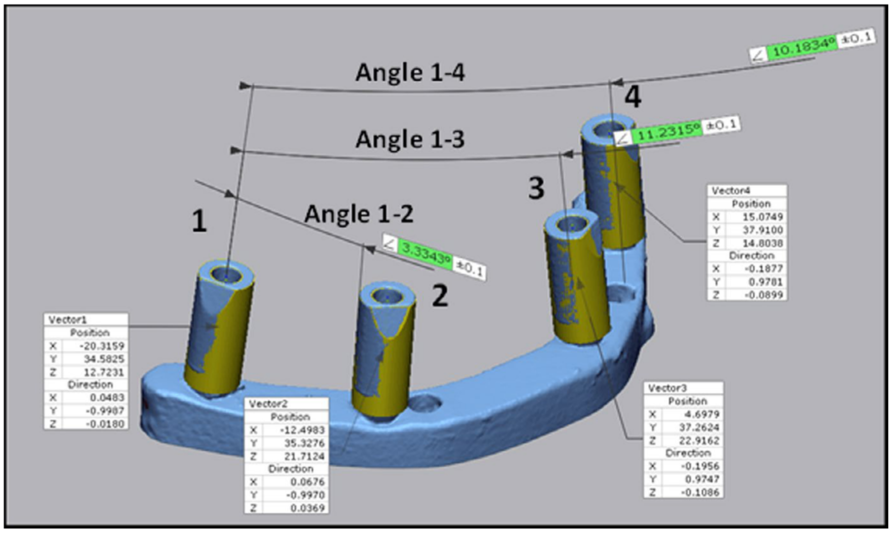

FIGURE 5 Angle measurement setup for intraoral and extraoral scanning comparison

scans of the same case from IOS and MIOS groups were 3D compared with the reference surface and RMS values used for the trueness analysis.

Following this protocol, precision and trueness data were calculated for each of 10 cases. Additionally, a direct comparison between IOS and MIOS 3D surfaces was made. In this case, a scan from the MIOS group was considered as the reference, and RMS values were calculated.

Statistical analysis was performed with Matlab (MathWorks) software. Shapiro–Wilk normality tests were carried out, and depending on the results, the Wilcoxon signed-ranks test or paired samples *t*-test was applied for the estimation of statistically significant differences between measurements. The level of significance was set at 0.05.

3 | RESULTS

The results of distance precision measurements for RS, IOS, and MIOS groups are shown in Figure 6 (data are shown as boxplots with median, 25th–75th percentiles, and whiskers) (Morel, 2018). The precision of the IOS scanner was decreasing with increased distance between the scan bodies. Also, it can be noted that in vitro scanning (MIOS) had better precision than in vivo one (IOS). However, a statistically significant difference between IOS and MIOS groups was found only for the largest distance between scan bodies (1–4).

Results of in vivo and in vitro scanning trueness in each distance for different groups are presented in Figure 7. Results show that trueness was comparable for both intraoral and extraoral scanning. Means were lower for 1–2 and 1–3 distances in the MIOS group. Higher deviations in 1–4 distance were found in the IOS group. However, a statistically significant difference between IOS and MIOS groups was found only for 1–3 distance between scan bodies. Results for accuracy of the distance measurements are summarized in Table 1.

Results of angle deviations between scan bodies resulting from different scanning modalities are presented in Figures 8 and 9. Figure 8 shows the precision measurements of angles between each pair of scan bodies for all groups. In vitro scanning resulted in fewer deviations as compared with the in vivo scanning. Also, a tendency of increase in deviations can be noticed with increased distance between the scan bodies. No statistically significant differences were found between IOS and MIOS groups. The results of angle trueness are presented in Figure 9. A statistically significant difference in angulation was found only between 1–4 scan bodies. Table 2 summarizes the accuracy measurements of angulation.

Scan surface deviations in different groups are presented in Table 3. Precision results show the tendency of better precision in the MIOS group; however, no statistically significant differences between IOS and MIOS were found. As for the trueness, a statistically significant difference between IOS and MIOS groups was seen.

A comparison between IOS and MIOS 3D surfaces is shown in Table 4. The difference between 3D images obtained in vivo and in vitro scanning conditions was similar, as found in precision and trueness analysis of 3D surfaces.

4 | DISCUSSION

The present study indicated that intraoral conditions may influence the accuracy of the scanning. It has to be considered, however, that for most of the characteristics evaluated in the study, trends of decrease in accuracy and no statistically significant differences were found. Therefore, the null hypothesis of the study was only partially accepted.

This is the first study, which evaluated the accuracy of digital implant impressions when using the true reference approach for full-arch scanning. It was shown before that the precision of the dental arches scanned under in vivo situation has considerably decreased as compared with in vitro scanning (Flugge et al., 2013). However, obtaining the true reference measurements for the evaluation of trueness in a clinical study is problematic, as high-accuracy equipment (laboratory or industrial scanners, coordinate measurement

TABLE 1 Means, standard deviations, medians, interquartile range (IQR), minimal (Min) and maximal (Max) values, *p*-values of differences of precision, and trueness measurements of distances between the scan bodies in IOS, MIOS, and RS groups

	Precision, µm							Trueness, µm						
Data	Mean	SD	Median	IQR	Min	Max	diff. p	Mean	SD	Median	IQR	Min	Max	diff. p
IOS 1–2	10	3	10	5	7	17	0.770[a]	18	7	19	10	4	29	0.485[b]
MIOS 1–2	15	15	10	5	4	55		16	10	12	13	2	33	
RS 1–2	2	0.8	2	1	0.6	3		----	----	----	----	----	----	
IOS 1–3	24	13	20	19	10	44	0.922[a]	21	12	17	12	10	42	0.049[a]
MIOS 1–3	23	16	17	10	11	66		12	7	11	8	2	26	
RS 1–3	2	1	2	2	0.6	4		----	----	----	----	----	----	
IOS 1–4	44	18	41	13	11	77	0.002[a]	32	19	29	34	7	61	0.850[b]
MIOS 1–4	31	16	32	13	8	64		30	14	28	24	8	52	
RS 1–4	2	1	2	2	0.8	4		----	----	----	----	----	----	

[a]Indicates Wilcoxon signed-rank test *p*-value.
[b]Indicates paired sample *t*-test *p*-value.

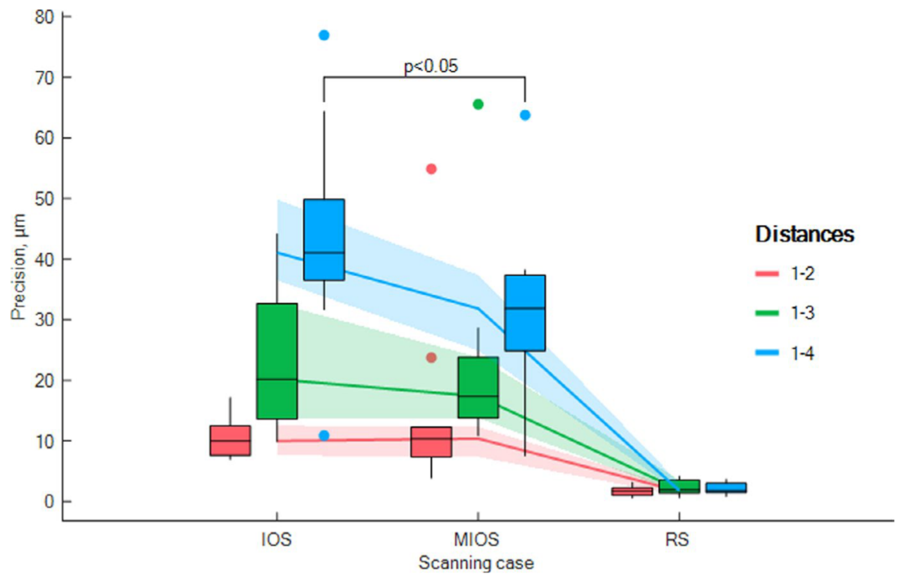

FIGURE 6 Precision evaluation of distances between 1–2, 1–3, and 1–4 scan bodies in IOS, MIOS, and RS groups. Boxplots represent medians and interquartile ranges (IQR)

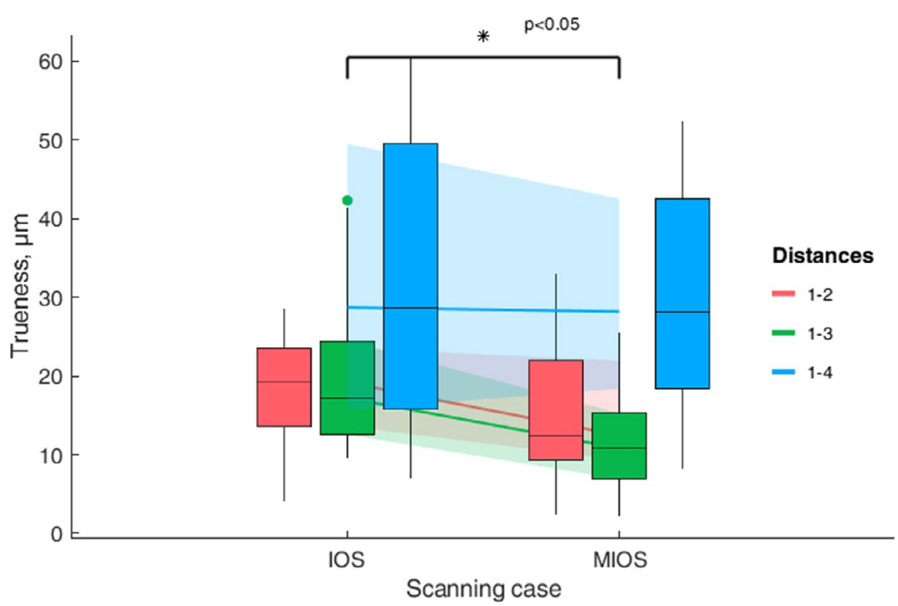

FIGURE 7 Trueness evaluation of distances between 1–2, 1–3, and 1–4 scan bodies in IOS and MIOS groups. Boxplots represent medians and interquartile ranges (IQR). Translucent colored areas represent IQR change and horizontal lines connecting the boxes—median change between the groups. Dots represent outliers

machines, etc.) cannot be applied directly to patients. Intraoral scanning of a geometric shape of known dimensions can be applied; however, it does not fully represent the situation when dental implant scan bodies are scanned intraorally (Keul & Güth, 2020). Also, an industrial 3D scanner was suggested for direct patient scanning; however, this approach can be applied only for the anterior teeth (Nedelcu et al., 2018). The concept applied in this study allowed scanning an edentulous situation with 4 implant scan bodies with IOS under in vitro and in vivo conditions. Using this methodology, the situation could also be scanned with a high-accuracy laboratory scanner obtaining the true reference data.

Accuracy, according to ISO 5725–1, consists of precision and trueness (ISO-Norm 5725–1:1994 "Accuracy (trueness and precision) of measurement methods and results—Part 1: General principles and definitions"). Precision describes the closeness of repeated measurements to each other. Higher precision means a better predictable result of the measurement. Trueness shows the measurement discrepancy to the true value. Accuracy of intraoral digital impressions can be estimated using distance (Andriessen et al., 2014; Mangano et al., 2016; Mutwalli et al., 2018), angulation (Andriessen et al., 2014; Mangano et al., 2016), or surface (Ender et al., 2013; Hayama et al., 2018; Mangano et al., 2016) measurements. Also, there are different approaches to evaluate the trueness and precision—using means (Mutwalli et al., 2018) or RMS values of the distances between superimposed surfaces (Hayama et al., 2018). In the current study, RMS values were used comparing surface deviations of 3D images.

Larger differences between the groups were noticed with increased distance between the implants. This could be explained as scanning larger areas involves more image stitching, which negatively affects the accuracy. Other studies also confirm this, showing accumulation of deviations when scanning larger or more posteriorly in the arch-located areas (Gimenez-Gonzalez et al., 2016; Iturrate et al., 2019; Vandeweghe et al., 2016). The accuracy differences

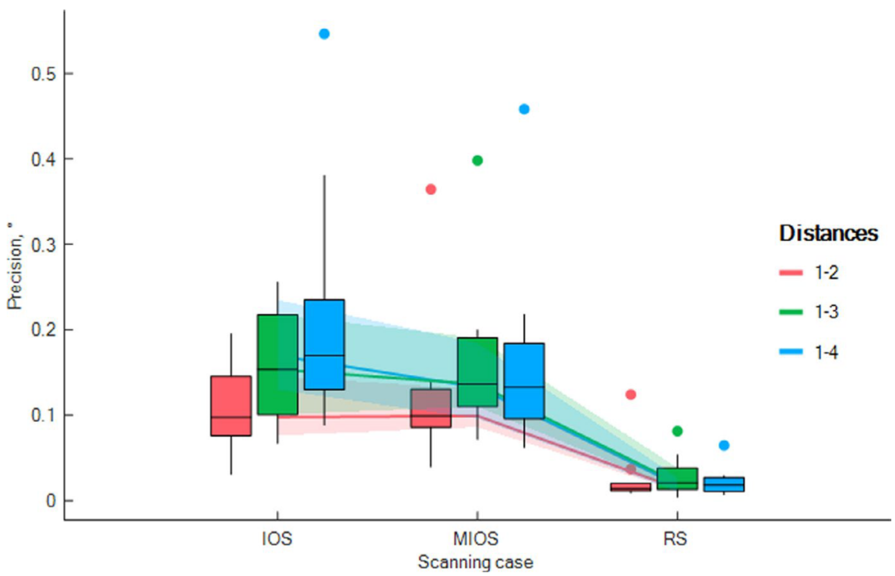

FIGURE 8 Precision evaluation of angulations between 1–2, 1–3, and 1–4 scan bodies in IOS, MIOS, and RS groups. Boxplots represent medians and interquartile ranges (IQR). Translucent colored areas represent IQR change and horizontal lines connecting the bars—median change between the groups. Dots represent outliers

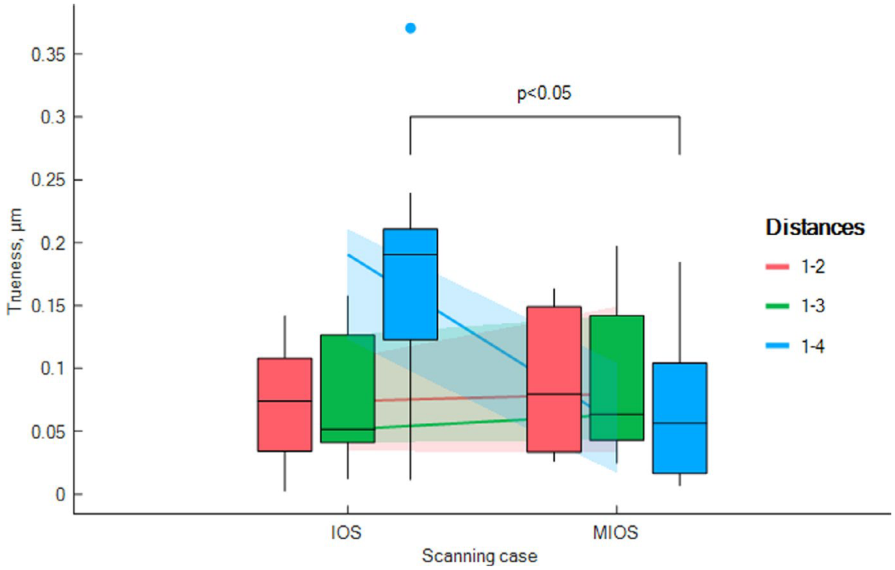

FIGURE 9 Trueness evaluation of angulations between 1–2, 1–3, and 1–4 scan bodies in IOS and MIOS groups. Boxplots represent medians and interquartile ranges (IQR). Translucent colored areas represent IQR change and horizontal lines connecting the bars—median change between the groups. Dots represent outliers

TABLE 2 Means, standard deviations, medians, interquartile range (IQR), minimal (Min), maximal (Max) values, *p*-values of differences of angles between the scan bodies in IOS, MIOS, and RS groups

	Precision							Trueness						
Data	Mean	SD	Median	IQR	Min	Max	diff. p	Mean	SD	Median	IQR	Min	Max	diff. p
IOS 1–2	0.11	0.05	0.10	0.07	0.03	0.20	0.625[a]	0.07	0.05	0.07	0.07	0.00	0.14	0.502[b]
MIOS 1–2	0.12	0.09	0.10	0.04	0.04	0.36		0.09	0.06	0.08	0.12	0.03	0.16	
RS 1–2	0.02	0.04	0.01	0.01	0.01	0.12		----	----	----	----			----
IOS 1–3	0.16	0.07	0.15	0.12	0.07	0.26	0.770[a]	0.07	0.05	0.05	0.09	0.01	0.16	0.575[b]
MIOS 1–3	0.16	0.09	0.14	0.08	0.07	0.40		0.09	0.06	0.06	0.10	0.03	0.20	
RS 1–3	0.03	0.02	0.02	0.03	0.00	0.08		----	----	----	----	----	----	----
IOS 1–4	0.22	0.14	0.17	0.11	0.09	0.55	0.414[a]	0.18	0.10	0.19	0.09	0.01	0.37	0.01[b]
MIOS 1–4	0.16	0.11	0.13	0.09	0.06	0.46		0.07	0.05	0.05	0.09	0.01	0.18	
RS 1–4	0.02	0.02	0.02	0.02	0.01	0.06		----	----	----	----	----	----	----

[a]Indicates Wilcoxon signed-rank test *p*-value.

[b]Indicates paired sample *t*-test *p*-value.

between the MIOS and IOS groups could also be less expressed, as the same scan bodies were scanned in both situations, and there was no need to disconnect and connect them. The manufacturing tolerances of the scan bodies and repositioning accuracy were addressed in the literature as possible factors that could negatively influence the accuracy of digital impressions ((Schmidt et al., 2019) (Semper-Hogg et al., 2013)). Therefore, the current study design allowed to evaluate the differences between intraoral and extraoral scanning, excluding the effect of manufacturing tolerances of scan bodies and their repositioning. Hence, smaller errors should be expected than in clinical situations.

As in vivo studies investigating the trueness of intraoral scanners were not found, results in only in vitro studies can be compared. Several in vitro studies have evaluated trueness and precision addressing distance, angle, and 3D surface parameters when taking full-arch optical implant impressions (Gimenez-Gonzalez et al., 2016; Gintaute, 2015; Iturrate et al., 2019; Manganao et al., 2019; Mangano et al., 2016). Iturrate et al. (2019). assessed trueness and precision of distance, analyzing Trios 3, 3 M True Definition, and iTero intraoral scanners on a full-arch model with four implants. Similarly, as in the current study, three distances between the scan bodies were evaluated and compared. Precision varied from 14 ± 15 μm to 118 ± 97 μm (10 ± 3 μm and 44 ± 18 μm in the present study), and trueness mean values ranged from 17 ± 15 μm–189 ± 70 μm (12 ± 7 μm–32 ± 19 μm in the present study). Similarly, higher deviations in trueness in full-arch in vitro model with 6 implants were reported by other research evaluating Trios, CS3500, ZFx Intrascan, and Planscan IOS intraoral scanners (Mangano et al., 2016). Mean precision and trueness of the Trios scanner were found to be 67.0 ± 32.2 μm and 71.6 ± 26.7 μm, respectively. These differences can be explained by the specific scanning technique and an older version of the scanner used in that study.

Regarding angulations, several in vitro studies reported 0.21 ± 0.17° (Gimenez-Gonzalez et al., 2016) and 0.17 ± 0.14° (Gintaute, 2015) deviations when trueness was considered. In the present study, IOS and MIOS trueness for angulation was found to be 0.11 ± 0.08° and 0.08 ± 0.05°, respectively. These differences can be attributed to the different study designs, the shape of the scanned object, number and angulation of implants, scanning strategy, different types of IOS, software versions, shapes of the scan bodies, etc.

Accuracy of the 3D surfaces obtained with intraoral scanners is critical, as based on this, the CAD files of scan bodies are aligned. Moreover, these surfaces can be used later for the bite registrations and alignments with other images (e.g., 3D face scans, CBCT images). A less accurate 3D surface leaves more room for the alignment error of the library CAD file. In vivo scanning caused more deviations when precision and trueness of 3D surfaces were evaluated. Thus, intraoral conditions had a significantly negative effect on the accuracy when 3D surfaces were considered. Intraorally, the tip of the IOS is manipulated in the limited space area, and more images are accumulated, and image stitching is compromised by the movement of the patient, mucosa, and tongue. Therefore, scanning becomes

TABLE 3 Trueness and precision measurements in IOS, MIOS, and RS groups, representing RMS (root mean squared) distance between the surfaces

	Precision, µm							Trueness, µm						
Data	Mean	SD	Median	IQR	Min	Max	diff. p	Mean	SD	Median	IQR	Min	Max	diff. p
IOS	97	27	107	38	55	132	*0.114**	249	87	230	123	134	391	*0.009**
MIOS	78	25	76	38	52	122		137	45	118	53	96	228	
RS	11	4	10	6	6	17	----	----	----	----	----			----

*Indicates paired-sample *t*-test *p*-value.

TABLE 4 Comparison of surface deviation between MIOS and IOS groups

Difference RMS, µm			
Mean	SD	Median	IQR
144	51	136	70

more prone to errors (Gimenez et al., 2014; Gimenez-Gonzalez et al., 2016). Due to this, results of in vitro studies should be interpreted with caution.

It is very difficult to define the clinically acceptable linear and surface deviations, as this will depend on the number and angulation of implants, type of the connection, manufacturing tolerances of the components, and other factors (Rutkunas et al., 2020). Clinically acceptable misfit values of final implant-supported restoration from 10 µm (Brånemark, 1983) to 150 µm (Jemt, 1991) were reported in the literature. Based on simple calculations, 100 µm for linear and 0.4° for angle measurements were proposed by another group of authors (Andriessen et al., 2014). Considering additional sources of errors generated during the workflow, deviations of digital impressions must be kept as low as possible. In this study, maximum distance deviation values were below 150 µm; however, 3D surface deviations were approaching or exceeding this value. Also, the maximum values of angle deviations were close to or above the 0.4° value.

Light reflections from the titanium bar could negatively influence the scanning accuracy (Kurz et al., 2015). To eliminate this effect, the bar was sandblasted before scanning both intraorally and on the master model.

Stitching the images of the edentulous areas is one of the biggest challenges for the intraoral scanners. Therefore, adding various shapes of geometrical reference objects in the edentulous regions was suggested (Iturrate et al., 2019; Mizumoto et al., 2020). The metal bar represented a more favorable condition as compared with edentulous areas in the clinical situation, where mobile mucosa can cause significant scanning and image stitching problems. Therefore, it is likely that in the real clinical condition, the accuracy could be even more compromised, particularly in the edentulous mandible.

This study has attempted to simulate the clinical situation with four parallel scan bodies of the selected design. The number of implants, the distance and angulation between them, and the shape of the scan bodies also might influence scanning accuracy (Rutkūnas et al., 2017) (Flugge et al., 2016; Mizumoto et al., 2020). It was suggested that reducing inter-implant distance may decrease linear deviations occurring during optical impression taking in full-arch situations (Tan et al., 2019). The type of the scanner and scanning strategy can also play an important role, and results can vary with different IOS devices and software versions. Continually changing technologies of the intraoral scanners and software updates often compromise the validity of the already published research results. Therefore, more clinical studies involving different intraoral scanners are needed to validate digital full-arch implant impressions.

5 | CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

- A trend of an adverse effect of intraoral conditions on the accuracy of digital implant impression was observed, though the majority of linear deviations were not significantly different between in vitro (MIOS) and in vivo (IOS) groups.
- With increased distance between the scan bodies, there was a tendency to decrease in the accuracy parameters.
- Direct comparison of 3D surfaces between in vitro and in vivo groups revealed differences that could be of clinical significance (143 ± 51 µm).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Vygandas Rutkunas: Conceptualization (equal); Data curation (lead); Methodology (lead); Project administration (lead); Supervision (lead); Writing-review & editing (equal). **Agne Gedrimiene:** Conceptualization (equal); Data curation (equal); Methodology (equal); Writing-original draft (lead). **Mykolas Akulauskas:** Software (equal); Visualization (equal). **Vincent Fehmer:** Formal analysis (equal);

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DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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