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Accuracy, time efficiency and operator preference in edentulous arch scanning: a preliminary report

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KEYWORDS Intraoral scanning, Edentulous patient, Digital denture, Scanning accuracy, Scanning time, Scanning experience.

ABSTRACT

Aim The present *in vitro* study evaluated the accuracy of intraoral scanners (IOS) in a completely edentulous arches and analyzed the influence of operator experience on accuracy, also time efficiency and operator's difficulty perception related to IOS procedures.
Materials and methods Twenty participants were enrolled for the digital scanning procedure of a maxillary edentulous metal model using an intraoral scanner, Aadva iOS100 (GC Corp., Tokyo, Japan). Participants were divided in two groups according to their experience in intraoral scanning procedures: Inexpert (InE group) without any experience in dental scanning (n=10) and Experts (E group) composed of operators with at least 3 year of scanning experience with IOS (n=5). Five IOS procedures were repeated for each operator and exported as a correspondent Stereolithography (STL) file. The same model was scanned with a laboratory scanner (LSS) (D1000 3 Shape Copenaghen Denmark), obtaining an STL file of the model which has been used as a reference. Accuracy of IOS were evaluated using a surface adaptation software (Geomagic Design X). The time required for each scanning procedure, and the perceived difficulty level were recorded for all the participants. The data obtained about accuracy, scanning time and difficulty perceived were compared between the two groups using the T-test for independent samples. The same variables were also correlated with each other using the Pearson's coefficient.
Results The highest trueness was observed for the scans provided by E participants. Precision ranged from 95,89 to 79,36 respectively in E and InE operators. For both trueness and precision there were significant differences between the two groups ($p<0.05$). Regarding scanning time, the more experienced operators were faster than inexpert ones with a significant difference ($p<0.001$). The two groups reported also differences in terms of difficulty perceived. Pearson's correlation reported for time scanning a significant correlation with trueness $p<0.001$ and precision $p<0.05$ and between difficulty perceived and trueness $p<0.05$.
Conclusions Digital impressions accuracy was different in E and InE operators as well as the scanning times, that was correlated with both trueness and precision.

INTRODUCTION

The rehabilitation of completely edentulous patients with conventional complete dentures is still a very diffused and predictable treatment approach (1-3). However the recent advancements in digital technology have led to the use of computer-aided design and computer-aided manufacturing (CAD-CAM) technology in the design and manufacturing of complete dentures (CDs) (4). Recent studies reported easier clinical protocols using CAD-CAM processes compared to traditional methods (5,6), the use of materials with improved properties (7,8), better fit and retention of the CDs (9), reduction in chair-side and laboratory times (9,10) and overall reduction in clinical and laboratory costs (11). High patient and clinician satisfaction with CAD-CAM CDs has also been reported (12-14).
Additionally, some preliminary clinical reports on intraoral scanning (IOS), in partially and completely edentulous patients, are reported in literature with encouraging results in full digital restorations (15,16).
Moreover IOS eliminates patient discomfort related to conventional impression making, reduces potential impression deformation (expansion, shrinkage, distortion), limits the risk of spreading infections, simplifies working procedures for dentists and technicians and, lastly, it saves time and space normally spent on impression processing and transportation. One of the main advantages of the digital impression is to avoid the compression of the mucosa due to using conventional materials, thus obtaining a true mucostatic impression. On the other hand, IOS has been criticized about the possibility to register a functional impression as done in conventional workflows (16-18). Nevertheless the new generation of intraoral scanners are considered as suitable for scanning of extended or even completely edentulous ridges, even without reference markings, as suggested by some authors (19,20).
A potential limit of IOS in edentate condition is that it

can introduce inherent errors of alignment within the software; moreover the effects of scan size, type, time, and operator experience on the resulting accuracy are not fully understood (21-23). To date, there are few reports focusing on the feasibility and accuracy of intra-oral digital impressions for edentulous jaws, especially for the part of soft tissues.
As regards the accuracy of intra-oral scans for completely edentulous arches, some *in vitro* studies were conducted. In a recent study Patzelt et al. evaluated the feasibility of using contemporary IOSs to digitize edentulous jaws using different IOS systems compared to a laboratory scanner as reference. Their findings demonstrated higher deviations in the palatal areas with poorly traceable smooth surface appearances (24). It remains unclear whether IOS is a suitable option with regards to scan accuracy and scan time. Faulty stitching and summation of the acquired images due to poorly differentiated structures in edentulous jaws might be a potential reason of these errors. More recently Osnes et al. (25) investigated the precision of six intraoral scanners using the traditional method of measuring mean error, from these, they found that Aadva, 3Shape, CEREC and TDS produced scans potentially appropriate for clinical use revealing deviations lower than 0.3 mm in upper bound deviation.
In addition to the clinical point of view, lack of support in edentulous patients requires the dentist to hold the scanner in a free-floating position and can result in an unsteady hand leading to further errors (26). This aspect can also determine a different perception in operators due to their skills, and can have an effect on time and accuracy of IOS, as reported for dentate conditions.
In view of this scientific lacuna, the aim of this *in vitro* study was to evaluate the accuracy of IOS on a maxillary edentulous model performed by operators with different levels of scanning experience compared to a laboratory scanner considered as control. Furthermore the potential influence of the clinical experience, the operator's perception of level of difficulty, and the scanning time were evaluated.
The null hypotheses were three.
1 The level of experience did not influence the accuracy or the IOS, the scanning time and the perception of difficulty.
2 The scanning time is not correlated with the level of accuracy of IOS.
3 The perception of difficulties is not correlated with the level of accuracy of IOS.

MATERIALS AND METHODS

A group of 20 operators were randomly selected in the Prosthodontics Department of the University of Siena and were enrolled for the digital scanning procedure of an edentulous maxillary model made, of metal, using an

FIG. 1 Maxillary model mounted on phantom training unit.

intraoral scanner (Aadva iOS100; GC Corp., Tokyo, Japan). All participants were divided in two groups according to their experience in intraoral scanning procedures.
- Group 1, Inexpert composed of undergraduate dental students without any experience in dental scanning (n=10).
- Group 2, Experts composed of scanning operators with at least 3 year of experience with IOS (n=10).

The model was mounted on a phantom training unit simulating a clinical scenario under dry conditions with ambient light (Fig 1). All participants were initially instructed by a tutorial video demonstrating the step-by-step sequence of use sequence of the IOS. The scanning procedure started from the retrozigomatic fossae in the first quadrant, following the alveolar crest moving to the opposite side scanning the vestibular area, then the operator scanned the alveolar crest area from the left side to the right. A second scanning flow started through the retroincisive papilla, and finally covered all the palatal area proceeding in a zigzag movement until the post dam area. Clinically relevant success criteria for the IOS were introduced defining an accurate scan by the absence of lack of data ('scan holes'). Five scanning procedures were repeated for each operator and exported as a corresponding stereolithography (STL) file. The same model was scanned with a laboratory scanner (LSS) (D1000 3 Shape Copenaghen Denmark), obtaining an STL file of the model which has been used as a reference (control group).
Before starting the superimposition of the STL files, the definitive bearing base of the future prosthesis was designed on the reference STL file and was digitally transferred to the STL files obtained by IOS. The prosthetic supporting base was limited to the finish line determined in the model (Fig. 2).

Accuracy of data analysis

For trueness, the STL file of each operator was superimposed to the respective reference scan STL file using a surface adaptation software (Geomagic DesignX;

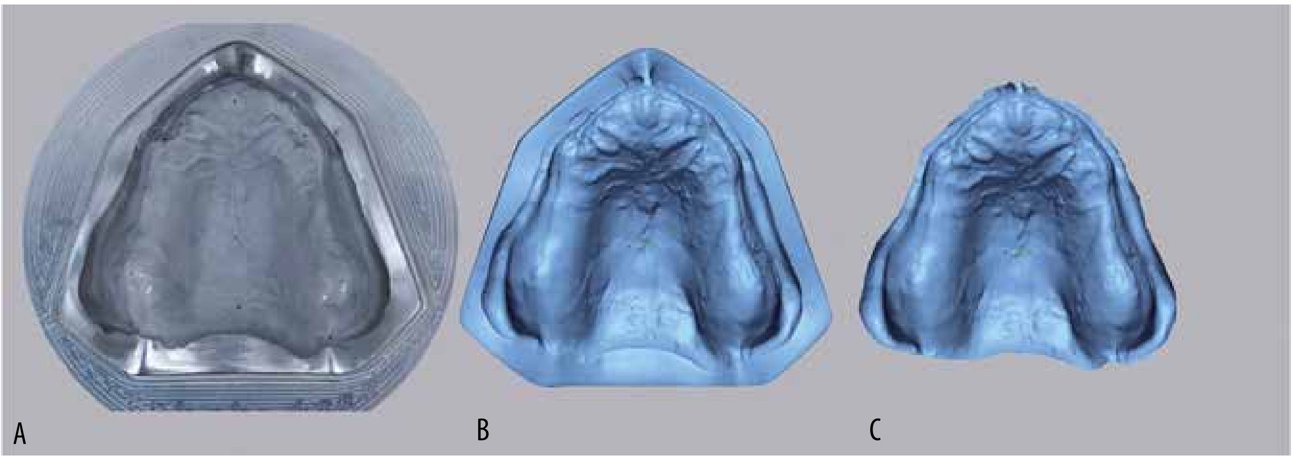

FIG. 2 Finish line of the model evaluated in the cad software.in

3D Systems Inc Rock Hill California USA) by the software's "best fit" algorithm; the software then automatically performed an accuracy analysis of the absolute values of distances between IOS and LSS. These values are visually displayed with a "color map" which shows the distances between models in different colors.
The distance limit used for the preparation of this color map was 0.1 mm. Thus the average deviation of the surface between the 2 bodies was recorded and the resulting 100 measurements were reported for statistical analysis. Precision was evaluated considering the scans of the same operator that were superimposed on each other using the previous software as reported for trueness evaluation. Specifically, the second, third, fourth and fifth scans were superimposed on the first scan. This process was repeated using the second, third, fourth and fifth scan as the 'base scan' for all scan sets, resulting in 4 combinations for each operator. Thus 200 measurements were obtained.

Time efficiency

Time efficiency was defined as the total work time needed to achieve a clinically acceptable IOS according to the described success criteria. The scan time was measured (in sec.) from the beginning to the end, including any time needed for retouching missing parts. During the scanning, a separate operator recorded the time taken with a digital stopwatch, and all times were averaged.

Operator's evaluation

Operators' evaluation comprised the perception on the level of difficulty of the impression procedure using Visual Analog Scales (VAS). All study participants reported their difficulty evaluation after the 5 scans by positioning a hash mark on a non-numerical 100 mm line. For analysis, the answers were transformed in a numerical value ranging from 0 to 100 (very difficult to not difficult).

Statistical analysis

Statistical analysis of the data was performed using SPSS 26 (IBM, Armonk, NY, USA). Data obtained from the scans superimposition, time efficiency and operator evaluation were evaluated for normal distribution using the Kolmogorov-Smirnov test.
T-test was assessed to evaluate the difference between the mean values obtained for trueness and precision in the two groups of participants, the level of significancy was assessed at 0.05. The same analysis was performed to evaluate the difference between the two groups in terms of scanning time and difficulty.
The Pearson's coefficient was evaluated to the correlation between scanning time, difficulty and accuracy in terms of trueness and precision. Level of significance was set at 0.05.

RESULTS

Kolmogorov–Smirnov test showed that the normality of the deviation measures was not violated. The means of trueness and precision and their standard deviation obtained from the operators of the two groups are reported in Table 1. The highest trueness (lowest values)

	Trueness [µm]			Precision [µm]		
Experience Group	Mean	SD	T-test signifi-cance	Mean	SD	T-test signifi-cance
InE	103,16	29,52	A	95,89	39,60	a
E	71,24	15,43	B	79,36	21,63	b

TABLE 1 Accuracy evaluation between two groups, T-test significance was $p<0.05$.

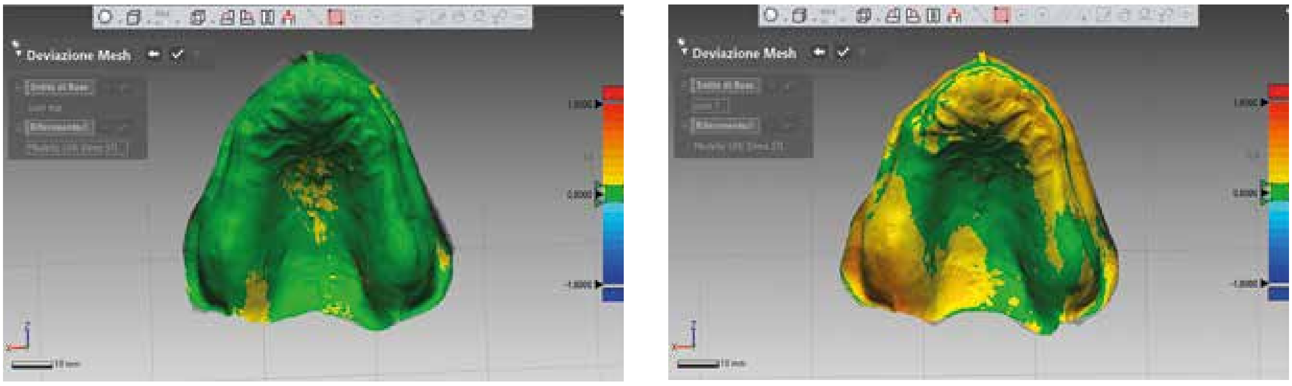

FIG. 3 Colormap showing selected images from superimposition of group of E and InE respectively in image A and B, with distance measured in millimeters.

was observed for the scans provided by expert operators. Precision ranged from 95,89 to 79,36 respectively in inE and in E operators. For both values trueness and precision reported significant differences between the two groups ($p<0.05$). Figure 3 shows colormaps of the trimmed surface deviation comparisons for representative samples from E and InE groups. The comparison obtained in the InE group reported the main discrepancies in the palatal area.

Regarding scanning time, E operators were faster than InE operators, $p<0.001$ (Table 2). A significant difference was also found between the two groups in terms of difficulty that resulted higher in the InE group (Table 3). Pearson's Correlation reported a significant correlation between time and trueness ($p<0.001$) and precision ($p=0.013$) and between trueness and difficulty ($p<0.001$). Trueness was negatively correlated with the perception difficulty ($p=0,004$).

DISCUSSION

The application of digital protocols in complete denture rehabilitations can simplify the treatment of the edentulous patient reducing clinical and laboratory procedures. The use of IOS in this field can be decisive and can reduce the patients discomfort (27,28). Nevertheless, digital scanners can introduce inherent errors of alignment within the software program. The effects of scan size, scanning time, and operator experience (21,23) are still underevaluated in the scientific literature regarding edentulous arches, in particular there is not any previous study evaluating the effect of operator experience in scanning edentulous arches.

The aim of this preliminary *in vitro* study was to evaluate accuracy of the IOS obtained by InE and E operators. It also evaluated the role of the scanning time and the difficulty perceived by the operators in the IOS accuracy that was evaluated as perviously reported by precision and trueness (29).

The results obtained refused all the proposed null hypotheses. The study suggests that digital impressions obtained by expert operators achieved better levels of accuracy. Scanning time differs by experience levels, it was around 50% lower in InE compared to E group, and it also had a significant correlation with accuracy. Lastly the operators perceived differently the difficulty levels, and this aspect was correlated with trueness.

The IOS system (Aadva scanner GC company) used was evaluated in a previous *in vitro* study (25) where it resulted as the most precise when compared to different IOS devices. However, there is not any study in the current literature yet reporting the results of the IOS influence on the experience of the operators in the

	Scanning time [s]		
Experience Group	Mean	SD	T-test significance
InE	193,20	28,56	A
E	95,20	8,57	B

TABLE 2 Scanning time evaluation between two groups, T-test significance was $p<0.001$.

	Difficulty level [%]		
Experience Group	Mean	SD	T-test significance
InE	39,80	3,42	A
E	18,20	10,73	B

TABLE 3 Difficulty level evaluation between two groups, T-test significance was $p<0.001$.

accuracy of edentulous arches.
Recent reviews reported that complete arch scans or larger arch spans had lower precision than tooth scans (30-32), probably because of the larger area involved; in particular, it seems that experience can be crucial when, due to the lack of teeth, the IOS does not have any reference point during the data acquisition.
Some previous studies evaluated the accuracy of high, medium and low experienced operators (33), however between medium and high experience little differences were reported, that is why it was decided to evaluate only the two extreme levels of experience: operators without any experience and experts.
Regarding the accuracy of IOS, many different techniques have been reported, though reference scan data from an industrial high-precision scanner is still regarded as the golden standard for measuring trueness (32). Comparing scan data through a best-fit alignment is also a well-accepted methodology. However this method can be criticized as data typically contains thousands of points, and scan alignment algorithms serve solely to minimize the mean distance between two sets of such points (regardless of clinical fit). Small areas of significant inaccuracy, as reported for tooth wear (34) or evaluating differences at a crown margin can be underestimated by large regions of accurate smooth surface alignment (35). A recent study by Osnes et al. (25) evaluating different IOS scanners, including the same used in the present study, specified that an error lower than 0.3 mm at the 99.5% most deviating aspect of the scan would be considered ineffective to a clinical impact. In fact the errors below a maximum of 0.2 mm were previously reported as clinically acceptable for CD (36). More recently, deviations in the posterior region of maxillary dentures were recorded during flasking, which almost reached 0.25 mm (37). However, it could be interesting to evaluate, in further studies, the extension and the position of the areas with critical values of accuracy. It was reported by Chebib et al. (20) and Joung et al. (38) in two recent *in vivo* studies accuracy can drop in areas, such as the inner border or the posterior area, that are certainly relevant for the retention of the prosthesis.
In the present study, it was decided to evaluate surface alignment differences using the absolute amounts of every deviation between two corresponding surfaces and subsequently calculating the average. Moreover with this method it was possible to evaluate the deviations compared to other studies that used similar comparisons. In fact some approaches have been used to describe deviations between digital scan data including root-mean-square deviations, average deviations, mean deviations, and absolute deviations (24,39). This methodological aspect in the evaluation of the precision might explain the higher values compared to the study published by Osnes, even if the studies evaluated the precision of the same scanner (25). Moreover, the current use of absolute amounts of every deviation might explain the higher deviations obtained in our study compared to other studies where it is supposed that the method was to consider positive and negative deviations. It can be assumed that the differences in the superimpositions can be reduced if the positive and negative values were considered instead of the absolute values.
Regarding the shorter scan times of the E operators obtained, this was expected, as the positive effect of IOS experience on scan time was demonstrated in previous studies (26,30,40). The difference was statistically significant between the two groups and also scanning time was correlated to accuracy level. This might indicate that even with the standardization of the scanning procedure, that was explained to all operators by a tutorial video before scanning, experience plays an important role in the control of the shaking movement and in the amount of data acquired by images.
The mean of the scanning time obtained in the two groups ranged from 95 to 195 sec. respectively in expert and non expert groups. These are higher in comparison to the data obtained by Schimmel (41), and this is probably due to the differences in the methodology, participants, and IOS devices. Additionally the values of this previous study of trueness and precision recorded in the edentulous maxilla were lower, therefore it can be speculated that this result is due to the smaller superimposition area that was reported in the ROI (region of interest) reduced of 2 mm from the border of the impression. The decrease in scanned area might be a factor for the higher accuracy found by Schimmel et al. and by Lo Russo et al. (42) , as an increase in the scanned edentulous area has been reported to negatively influence the accuracy of intraoral scans. Infact, as it was clarified in previous studies the main discrepancies in the edentulous IOS compared to *in vivo* conventional impressions and *in vitro* scans were reported in the periferial areas and in the inner seal (20,38,44), that is usually positioned around 2-4 mm from the external border. However, scanning time was correlated with high values of precision and trueness (less accurate superimpositions), it can be supposed that the shorter scanning procedures might be obtained by a more fluid movement in the acquisition, with fewer problems in recapturing the images by the scanner.
A comparison of the presented data to a previous study by Patzel et al. (24) that is one of the most cited in this field and it also evaluated the absolute deviations, seems not to be relevant due to the different technologies used for the scanning procedure. Their results also ranged from higher values of trueness and precision (respectively 591.8 µm and 698.0 µm) to lower values (44.1 µm and 21.6 µm) in the same parameters. However Aadva scanner obtained higher accuracy results in both E and InE groups compared to all the scanners evaluated except the Lava scanner that is not yet available on the market.
The perceived difficulty, as expected, was significantly reduced in the E operators. The data obtained in the InE

group, was similar to the results obtained in a previous study, conducted in dentate conditions, in which after 5 scans of 9 it was around 4 in a VAS scale from 0 to 10 (40). Probably the results of the inexpert group can be influenced by the number of the scans performed because of the effect of the learning curve obtained by the cumulated experience after each scan. Moreover, the level of difficulty recorded in the study is correlated with accuracy in terms of trueness, probably because the E operator can easily use the IOS device, so the data acquired can be more similar to the laboratory scan. However any comparison with previous studies can not be conducted because the experience was not considered.

Within the limits of this study we have to consider that the digital scans were performed in a phantom head to simulate the limited space to move the camera intraorally. Other factors, such as patient movement, the presence of saliva or varied light-reflecting due to different kinds of intraoral tissues, which are said to influence the accuracy, were not simulated. However, some recent studies have shown only minor differences of *in vivo* versus *in vitro* complete-arch scans with IOS devices, in terms of accuracy and precision (45,46).

Future studies increasing the sample size for the number of experienced and inexperienced operators would help to confirm the results of the current study. Clinical studies evaluating the suitability of IOS for CD rehabilitations under *in vivo* conditions should also be performed. Controlled trials, comparing clinical- and patient-reported outcomes with conventional and digital CD obtained with digital scans would be of particular interest.

CONCLUSION

Based on the findings of this preliminary in vitro study, the following conclusions can be drawn.

Digital impressions performed by operators of two experience levels showed different levels of accuracy.

Scanning times differ by experience levels and accuracy, also the operators reported differences in the difficulty level, which is correlated with trueness.

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All authors gave final approval

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