Comparison of the accuracy of optical impression systems in three different clinical situations

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Submitted October 3, 2019; accepted July 1, 2020
ABSTRACT

Purpose: To investigate the differences in accuracy (trueness and precision) of five different optical impression systems. **Materials and Methods:** The accuracy of the following optical impression systems was tested: (1) CEREC Bluecam (BL; Dentsply Sirona), (2) CEREC Omnicam (OM, Dentsply Sirona); (3) PlanScan (PL; Planmeca); (4) True Definition Scanner (TD; 3M ESPE); and (5) Trios 3 (TR; 3Shape). A standard plastic study model represented a patient with a fully dentate maxilla (ANA-4 V CER, frasaco). Three clinical situations were simulated: Patient 1 (P1): fully dentate; Patient 2 (P2): anterior partial edentulism (two missing incisors); and Patient 3 (P3): posterior partial edentulism (P3) (missing premolar and molar). The models were scanned with a reference scanner (iScan D104i, Imetric), and the digitalized models were used as reference for all comparisons. Then, optical impressions were made for the three clinical scenarios (n = 10 per group). **Results:** In situation P1, the TD group provided the highest trueness (180.2 ± 46.3μm). In situation P2, the highest trueness was found in the TD (97.9 ± 27.6 μm) and TR (105 ± 9.5μm) groups, and in situation P3, TR had the highest trueness (P < .05) with a median RMS value of 76.2 ± 5.6 μm. In terms of precision, TR provided the highest precision (P < .05) in all three clinical situations, with RMS values 76.7 ± 26 μm for P1, 46.8 ± 14.1 μm for P2, and 39.7 ± 9.1 μm for P3. **Conclusion:** Two optical impression systems (TR and TD) were superior to the other tested systems in most of the measurements. However, none of the tested systems was clearly superior with respect to both trueness and precision. *Int J Prosthodont* 2021. doi: 10.11607/jip.6748
INTRODUCTION

The digital impression systems, today known as intra-oral scanners (IOS; intraoral scanner) were introduced in dentistry in the 1980s. Since Professor François Duret’s initial conception and development of a completely digital single unit reconstruction, substantial evolution was made in the area of digital dentistry. Nowadays, manufacturers are able to provide the dental community with technology that enables practitioners to take digital impressions even in more complicated clinical situations, such as in the presence of dental implants or for carrying out more complex full-arch rehabilitations. In the last thirty years, digital dental technology has evolved continuously, with a growing number of manufacturers offering new IOSs. Optical impression-taking is currently already part of the daily clinical procedures of many dentists, the IOS being an integral part of the equipment of the modern dental office.

The use of 3D cameras offer many advantages over conventional impressions using elastomeric impression materials, both for the patient and the dentist. Indeed, several studies have demonstrated a higher efficiency of the digital process compared to the conventional one. In addition, IOS systems may be an additional asset for patient communication, providing an intraoral image immediately visible on a screen, as well as assisting in diagnosis and treatment planning. They may also facilitate the everyday life of the practitioner, by offering the possibility of easily erasing and repeating a specific part of an impression, by controlling the final result of a preparation or a restoration with analysis tools, or by easily storing patient data. Finally, the risk of cross-infection with the laboratory is eliminated with the use of optical impressions, and
a better collaboration between the clinician and the technician can be established thanks to a facilitated communication.²

IOSs and the associated computer-aided design/computer-aided manufacturing (CAD/CAM) techniques have changed the workflow process in restorative dentistry, nowadays called the “digital workflow”. In this new digital workflow, a 3D camera is used to capture the intraoral situation, namely the tooth surfaces as well as the surrounding soft tissues. A 3D digital model of the patient’s jaw is thus directly created, thereby eliminating the need for a physical model for the manufacturing of a restoration.⁹ Through the use of a virtual model and a CAD/CAM software, chair-side single-unit restorations may be achieved in a single session. In more complex cases where a physical working model is needed, the latter can be fabricated from the virtual file using rapid prototyping technology.¹⁰⁻¹²

In restorative dentistry, an accurate impression remains a crucial factor for the production of a well-fitting restoration.¹³ It is therefore necessary to determine the reliability of the IOSs present on the market. The accuracy of an impression method is described by the combination of two notions, trueness and precision (ISO 5725),¹⁴ trueness being the comparison between each impression tested and the original geometry, thus representing the proximity of the impression to the real geometry. Precision describes the differences between the impressions within a test group and represents reproducibility, i.e. the frequency with which the same impression is achieved with the same outcome.¹²,¹⁴

To date, impression-taking with elastomeric impression materials remains the “gold standard”.¹³ Numerous in-vitro studies have compared the accuracy of conventional
elastomeric impressions with that of digital impressions, proving the performance of IOSs is compatible with clinical requirements.  

In recent years, dental manufacturers have introduced many new IOSs, and practitioners' interest in optical impression systems has increased. Different IOSs, design software and milling machines are introduced to the dental market every year. In this new era of digital dentistry where the clinical life of dentists and dental technicians constantly changing, many questions remain unanswered so far. It is therefore essential to assess whether differences in accuracy exist between the new digital impression devices, and if so, which ones are the most accurate.

Therefore, the objective of this in-vitro study was to evaluate the differences in accuracy (trueness and precision) of five different digital impression systems. The null hypothesis is that all digital impression systems are equally accurate and that there are no statistically significant differences in accuracy when used in different clinical situations.

MATERIALS AND METHODS

In the present study, five optical impression systems were evaluated, and their accuracy was compared to that of a well-established reference scanner recommended for high-accuracy scanning of dental models (iScan D104i, Imetric 3D SA, Courgenay, JU, Switzerland).
Validation of the reference scanner

The accuracy of the laboratory scanner selected as reference scanner for this study was evaluated by using it to scan a reference object of which the precise dimensions are known and provided by the manufacturer (BRICK 2X4, LEGO®, The Lego Group, Billund, SL, Denmark).

For the assessment of the precision, the LEGO® BRICK 2X4 was scanned ten times (n=10), and the obtained data files were saved in Standard Tessellation Language (STL) format. A dedicated 3D inspection software (Geomagic Control X, 3D Systems Inc, Rock Hill, SC, USA) was used to compare the 10 STL data files by pairs. The 3D comparison was performed by superimposing each pair of STL data files according to the “Best Fit Method”, where all possible orientations are calculated and the one with the best volume/object-to-object combination is selected. The 3D differences for each point of the two surfaces were calculated and the root mean square (RMS; \( \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{1i}-x_{2i})^2} \)) was computed by the software and used to represent the difference between the two scans.

The trueness of the reference scanner was evaluated using an analysis software (OraCheck, Cyfex AG, Zurich, ZU, Switzerland) to measure the length of LEGO® BRICKS on the scans. The average value obtained from the 10 scans was compared with the exact dimensions provided directly by the manufacturer.

Reference models

The chosen reference model for the experiment was a standard plastic study model (ANA-4 V, frasaco GmbH, Tettnang, BW, Germany) used to represent a maxillary dental arch. Three clinical situations were simulated by modifying the configuration of the dentition on the
study model. A clinical situation of a patient with a full arch was simulated by using the model in its fully dentate state (Patient 1; P1). Two clinical situations of patients presenting with partial edentulism were mimicked by removing specific teeth on the study model. An anterior gap situation was simulated by removing adjacent lateral and central incisors, creating a two-unit anterior gap (Patient 2; P2), while a two-unit posterior gap was created by removing an adjacent second premolar and first molar (Patient 3; P3). The reference model was scanned for each of the three previously described situations (P1-3) with the laboratory reference scanner, and the scan data was saved in STL format (REF 1-3).

Tested intraoral scanners

Five optical impression systems commonly used and presenting with different characteristics were selected for this in-vitro study (Table 1), namely the BL (CEREC Bluecam®, Dentsply Sirona Inc, York, PA, USA), the OM (CEREC Omnicam®, Dentsply Sirona Inc, York, PA, USA), the PL (PlanScan®, Planmeca Oy, Helsinki, Finland), the TD (True Definition®, 3M™, Maplewood, MN, USA) and the TR (Trios 3®, 3Shape®, Copenhagen, Denmark).

Digital Impressions

The three simulated patient situations were scanned using the five selected IOS systems, starting with P1, followed by P2 and P3. The digital impressions were taken according to each manufacturer’s instructions concerning scanning path strategy as well as surface preparation. Ten digital impressions were made (n=10) on each model (P1-3) with each of the IOS systems. All models were first scanned using the three systems not needing surface preparation, namely
OM (CEREC Omnicam®), TR (Trios 3®), and PL (Planmeca PlanScan®). The models were prepared thereafter using a matting powder (CEREC Optispray®, Dentsply Sirona Inc, PA, USA) before scanning with the BL (CEREC Bluecam® ), while they were prepared with a dusting powder (High-Resolution Scanning Spray, 3M™, MN, USA) before use of the TR (True Definition®). The scan data were directly exported from the acquisition unit (OM, BL, TR, PL) or sent for post-processing (TD) and then exported in an STL format. All the impressions were made by a single operator (MD) after training in the use of all the IOSs.

Scan file preparation for comparisons

The obtained STL data from the ten scans of each model using the five IOSs were analyzed with a 3D inspection software (Geomagic Control X) by means of 3D comparison. The STL data of the tested groups were thereafter superimposed using the “Best Fit Method”. The 3D differences were calculated and the root means square (RMS) was used to evaluate the compliance of the tested superimposed data \( \text{RMS} = \frac{1}{n} \sum_{i=1}^{n} (x_i - x_{2i})^2 \).}

Analysis of Accuracy

The trueness (ISO 5725-1) of each IOS system was assessed by comparing the digital impressions with the actual original geometry of the model, meaning all the STL data \((n=10)\) from each tested group (BL, OM, PL, TD, TR; in P1-3) were superimposed with the corresponding reference scans made with the laboratory scanner (REF 1-3).

The precision or reproducibility of the IOSs was evaluated by comparing the digital impressions within each test group in each simulated situation, meaning the STL data \((n=10)\) for
every tested group and situation (BL, OM, PL, TD, TR; in P1-3) were superimposed among themselves.

**Statistical analysis**

Non-parametric distribution was confirmed using the Kolmogorov-Smirnov test. All the comparisons were therefore performed using a Kruskal-Wallis test followed by the Dunn-Bonferroni adjusted post-hoc test, to show homogenous subset based on rank. The significance level was set at $p<0.05$. Statistical analysis was performed using SPSS statistical software release version 22.0 (IBM Corporation, Armonk, NY, USA).

**RESULTS**

**Accuracy of the reference scanner**

The 10 STL data files of the LEGO® BRICK scans were superimposed and compared by pairs, resulting in a total of 45 comparisons. The average value for precision over the 45 comparisons was 22.8μm ± 17.5.

The average length of the LEGO® BRICKS measured on the 10 STL data files was 1.0μm ± 3.7 larger than the dimensions provided by the manufacturer. This difference was not statistically significant.
Trueness of the tested intraoral scanners

Each model (P1-3) was scanned ten times with each IOS system, resulting in a total of 150 digital impressions, which were subsequently compared to the corresponding reference scans (REF 1-3), enabling to calculate a measurement of trueness (Table 2; Fig 1).

In the situation of a fully dentate arch (P1; Fig 2), the lowest RMS value, and therefore the highest trueness, was found for TD, with a median RMS value of 180.2µm ± 46.3 (p<0.05). Concerning the model simulating an anterior gap (P2; Fig 2), the highest values of trueness were measured in groups TD and TR, with RMS values of 97.9µm ± 27.6 and 105µm ± 9.5, respectively. Groups TD and TR were not statistically different among each other, but were significantly different from the other groups (p<0.05). Finally, in the situation with a posterior gap (P3; Fig 2), the highest trueness was found for TR (RMS=76.2µm ± 5.6; p<0.05), whereas PL showed the lowest trueness (RMS=266.5µm ± 50.1).

Precision of the tested intraoral scanners

All STL files for each IOS system in each situation (P1-3) were compared within each group, resulting in 45 superimpositions per group per situation, meaning a total of 225 comparisons from which the measurements for precision were subsequently calculated (Table 3; Fig 3).

The IOS system showing the highest precision was TR, and this was the case in all of the tested situations (RMS: P1 = 76.7µm ± 26; P2 = 46.8µm ± 14.1; P3 = 39.7µm ± 9.1; p<0.05). The lowest precision in the situation with a complete arch (P1), was found for PL (191.2µm ± 60.3;
Both BL and PL showed the lowest precision in the models mimicking anterior and posterior gaps (RMS: BL-P2 = 100.2µm ± 213.2; PL-P2 = 175.6µm ± 98.9; BL-P3 = 90.3µm ± 136.9; PL-P3: 108.9 µm ± 39.1; p<0.05).

DISCUSSION

The purpose of this in-vitro study was to evaluate the accuracy, i.e. the trueness and precision of five digital intraoral impression systems in complete-arch impressions of three different clinical scenarios.

This study revealed significant differences in the accuracy of the intraoral impression systems used to obtain the complete-arch digital impressions. While one system (TR) was significantly better than all the other tested systems with respect to precision in all clinical scenarios, the trueness of the systems differed between fully dentate situations and partially dentate situations (anterior/posterior gap). In the first scenario P1, TD was significantly better in terms of trueness than all the other tested groups, whereas in scenarios P2 and P3, TR achieved better trueness values. On the contrary, PL was found to be inferior to the other systems for both aspects of accuracy (trueness and precision) in all three scenarios. Consequently, on the basis of the present findings, the null hypothesis was rejected.

Several previous studies have investigated the accuracy of complete-arch impressions obtained by intraoral impression systems. Renne et al. evaluated the accuracy of seven digital scanners in an in-vitro study, including the TRIOS 3® (3 Shape®), which was found to provide the best combination of speed, trueness, and precision at complete-arch scans. These findings are in accordance with the results of the present study. In a recently published study, the accuracy
of nine IOSs was evaluated, \textsuperscript{21} where similar trends as in the present study were reported. The trueness and precision of the complete-arch scans made with three of the scanners (TRIOS\textsuperscript{®}, True Definition\textsuperscript{®} and CEREC Omnicam\textsuperscript{®}) were better than the ones made with the other tested scanners. \textsuperscript{21} Similarly, to the present study, one of the scanners presented the best outcomes for both parameters, trueness and precision (TRIOS\textsuperscript{®}, 3 Shape\textsuperscript{®}). \textsuperscript{21}

Despite the general similarity in the performance of the scanners between these studies, there are differences in the absolute values reported. Although, to date, a threshold for clinically acceptable accuracy has not yet been defined, in many studies the trueness and precision values were below 150 \textmu m, which would seem to be clinically acceptable. In the present study, the RMS values of trueness were found to be significantly higher, especially in the fully dentate scenario (P1).

A direct comparison with other published results is difficult to undertake, due to the presence of variations in study designs. Not only does the handling of the data via the analysis software differ among the studies, but also the interpretation of divergences after superimposition, as well as the three-dimensional comparison. \textsuperscript{17} In some studies, 20\% of the measured points (outliers) were excluded from the analysis, \textsuperscript{17} while in other studies, a trimming of the virtual model with the elimination of artefacts and/or the gingival area was performed before the three-dimensional comparison. \textsuperscript{15} In the present study, the virtual soft tissues were not eliminated from the 3D comparison, which could explain the differences in the values when compared to those of other studies.

Additionally, a significant difference was found between the three clinical scenarios, with P1 showing higher values than P2 or P3 in terms of trueness. In many studies, there are typical
deviation patterns in complete-arch scans across the incisal edges of anterior teeth and the buccal surface of molars, indicating a slight distortion of the posterior teeth. In the two scenarios with partial edentulism, P2 in the front area and P3 in posterior area, better results were found, which could be explained by the elimination of the areas where the most errors occur. Another possible explanation could be the learning curve of the operator, as the scanning process started with the full-arch scenario in this study.

In an in-vivo study, Ender et al. demonstrated that the precision of conventional impressions was similar or better than the digital scans of CEREC Bluecam®, CEREC Omnicam®, iTero®, Lava COS®, True Definition®, and TRIOS®, with the digital impression groups of Trios® and CEREC Omnicam® reaching the same high precision levels as conventional impression groups. The results of the present study are in agreement with the previous study reporting values of precision < 90μm for the group TR in all clinical scenarios, significantly better than the other groups, followed by group OM and TD.

All the comparisons in the present in-vitro study were undertaken after the digitalization of a master model with a laboratory 3D scanner (iScan D104i, Imetric 3D SA), which is recommended for high-accuracy scanning. The validation of the reference scanner used was an imperative precondition to this study, and the value of trueness inferior to 10μm was consistent with previous reports. The revealed accuracy of the reference scanner in this in-vitro study enhances the accurate results of all three-dimensional comparisons of tested groups.

Digital intraoral impression systems continue to develop rapidly. The accuracy of these new systems will remain a key factor for the production of adequately-fitting restorations in
restorative dentistry. Up to today, none of the systems seems superior to the others in all clinical scenarios. All systems have advantages and limitations and further research is needed, including standardized test methods to evaluate and compare the different intraoral impression systems.

CONCLUSIONS

From the results of the present in-vitro study, the following conclusions can be drawn:

1. In situations with anterior or posterior gaps, TR exhibited the highest accuracy (trueness and precision), followed by OM and TD.

2. In fully dentate situations, TD provided the highest trueness, however, not the highest precision.

3. TR provided the highest precision in all the three clinical situations.

4. PL showed the most inferior accuracy in all three clinical situations.

5. None of the tested systems exhibited superior accuracy in all tested clinical situations.

Acknowledgements:

The present study was supported by the University of Geneva with the tested scanners. The study was not financially supported by any companies.
REFERENCES


Fig 1 Comparison of trueness of all IOS systems; blue: P1 (complete arch); red: P2 (anterior gap); green: P3 (posterior gap)
Fig 2 3D comparison of trueness for all IOS systems
**Fig 3** Comparison of precision of all IOS systems; blue: P1 (complete arch); red: P2 (anterior gap); green: P3 (posterior gap)
### Table 1 Tested intraoral scanners and their characteristics

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Surface Preparation</th>
<th>Scanning Technology principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEREC Bluecam® (BL)</td>
<td>Powder</td>
<td>Triangulation/Single image</td>
</tr>
<tr>
<td>CEREC Omnicam® (OM)</td>
<td>None</td>
<td>Triangulation/continuous images</td>
</tr>
<tr>
<td>Planmeca PlanScan® (PL)</td>
<td>None</td>
<td>Triangulation/continuous images</td>
</tr>
<tr>
<td>True Definition® (TD)</td>
<td>Powder</td>
<td>Active wavefront Sampling/continuous images</td>
</tr>
<tr>
<td>Trios 3® (TR)</td>
<td>None</td>
<td>Confocal microscopy Laser/continuous images</td>
</tr>
</tbody>
</table>

### Table 2 Comparison of trueness of the five tested IOS systems

<table>
<thead>
<tr>
<th>Intraoral Scanner</th>
<th>Trueness (median RMS [µm] ± SD)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>P1 complete arch</strong></td>
<td><strong>P2 anterior gap</strong></td>
</tr>
<tr>
<td>Cerec Omnicam®</td>
<td>374.5 ± 41.5 ( b )</td>
<td>186.4 ± 26.5 ( b )</td>
</tr>
<tr>
<td>Trios 3®</td>
<td>325.3 ± 82.7 ( b )</td>
<td>105 ± 9.5 ( a )</td>
</tr>
<tr>
<td>Planmeca PlanScan®</td>
<td>345.3 ± 53.4 ( b )</td>
<td>274.2 ± 79 ( b )</td>
</tr>
<tr>
<td>Cerec Bluecam®</td>
<td>347 ± 149.2 ( b )</td>
<td>226.5 ± 408.6 ( b )</td>
</tr>
<tr>
<td>True Definition®</td>
<td>180.2 ± 46.3 ( a )</td>
<td>97.9 ± 27.6 ( a )</td>
</tr>
</tbody>
</table>
### Table 3: Comparison of Precision of the five tested IOS systems

<table>
<thead>
<tr>
<th>Intraoral Scanner</th>
<th>Precision (median RMS [µm] ± SD)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P1 complete arch</td>
<td>P2 anterior gap</td>
<td>P3 posterior gap</td>
<td></td>
</tr>
<tr>
<td>Cerec Omnicam®</td>
<td>122.7 ± 54.1 b</td>
<td>62 ± 25.5 b</td>
<td>64.6 ± 21.3 b</td>
<td></td>
</tr>
<tr>
<td>Trios 3®</td>
<td>76.7 ± 26 a</td>
<td>46.8 ± 14.1 a</td>
<td>39.7 ± 9.1 a</td>
<td></td>
</tr>
<tr>
<td>Planmeca PlanScan®</td>
<td>191.2 ± 60.3 d</td>
<td>175.6 ± 98.9 d</td>
<td>108.9 ± 39.1 c</td>
<td></td>
</tr>
<tr>
<td>Cerec Bluecam®</td>
<td>111.8 ± 28.6 b</td>
<td>100.2 ± 213.2 d</td>
<td>90.3 ± 136.9 c</td>
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<tr>
<td>True Definition®</td>
<td>153.3 ± 85.2 c</td>
<td>86.6 ± 46 c</td>
<td>71.2 ± 32.2 b</td>
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