Comparison of the Accuracy of Optical Impression Systems in Three Different Clinical Situations

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**Purpose:** To investigate the differences in accuracy (ie, 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); (2) CEREC Omnicam (OM); (3) PlanScan (PL); (4) True Definition Scanner (TD); and (5) Trios 3 (TR). A standard plastic study model represented a patient with a fully dentate maxilla. 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 (missing premolar and molar). The models were scanned with a reference scanner (IScan D104i), and the digitized 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 (median ± SD root mean square: 180.2 ± 46.3 μm). In situation P2, the highest trueness was found in the TD (97.9 ± 27.6 μm) and TR (105 ± 9.5 μm) groups, and in situation P3, TR had the highest trueness (P < .05; 76.2 ± 5.6 μm). TR provided the highest precision (P < .05) in all three clinical situations, with RMS values of 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;34:511–517. doi: 10.11607/ijp.6748

Digital impression systems, today known as the intraoral scanner (IOS), were introduced in dentistry in the 1980s. Since Duret’s initial conception of the digital workflow encompassing an optical impression and the completely digital development of a single-unit reconstruction, substantial evolution has occurred 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.1–4 In the last 30 years, digital dental technology has evolved continuously, with a growing number of manufacturers offering new IOS systems.2,5 Optical impression-taking is currently already part of
the daily clinical procedures of many dentists, and the IOS is an integral part of the equipment of the modern dental office.\(^5\)

The use of 3D cameras offers many advantages over conventional impressions using elastomeric impression materials, both for the patient and the dentist.\(^6\) Indeed, several studies have demonstrated a higher efficiency of the digital process compared to the conventional one.\(^6,8\)

In addition, IOS systems may be an additional asset for patient communication, as they provide an intraoral image immediately visible on a screen and can assist 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 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 facilitated communication.\(^2\)

IOS systems and the associated 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 arch 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, chairside 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 IOS systems available on the market. The accuracy of an impression method is described by the combination of two measures: trueness and precision (ISO 5725).\(^14\) Trueness is 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; ie, 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 to that of digital impressions,\(^15–17\) proving the performance of an IOS is compatible with clinical requirements.\(^6,17,18\)

In recent years, dental manufacturers have introduced many new IOS systems, and practitioners’ interest in optical impression systems has increased. Different IOS systems, design software, and milling machines are introduced to the dental market every year. In this new era of digital dentistry, where the clinical lives of dentists and dental technicians are constantly changing, many questions remain unanswered. It is therefore essential to assess whether differences in accuracy exist among 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 (ie, trueness and precision) of five different digital impression systems. The null hypothesis was 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 a well-established reference scanner recommended for high-accuracy scanning of dental models (IScan D104i, Imetric).\(^19\)

**Validation of the Reference Scanner**

The accuracy of the laboratory scanner selected as the reference scanner for this study was evaluated by using it to scan a reference object for which the precise dimensions were known and provided by the manufacturer (Brick 2 x 4, Lego).

For the assessment of precision, the Lego brick was scanned 10 times, and the 10 obtained data files were saved in standard tessellation language (STL) format. A dedicated 3D inspection software (Geomagic Control X, 3D Systems) was used to compare the 10 STL files by pairs. The 3D comparison was performed by superimposing each pair of STL data files \((n = 45\) comparisons) 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), used to represent the difference between the two scans, was computed by the software with the following formula:

\[\frac{\sum_{i=1}^{n}(x1i - x2i)^2}{n}\]

The trueness of the reference scanner was evaluated using an analysis software (OraCheck, Cyfex) to measure the length of the Lego brick on the scans. The average
value obtained from the 10 scans was compared to the exact dimensions provided directly by the manufacturer.

Reference Models
The chosen reference model for the experiment was a standard plastic study model (ANA-4V, Frasaco) 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 created 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 situations with the laboratory reference scanner, and the scan data were saved in STL format (REF 1–3, respectively).

Tested Intraoral Scanners
Five commonly used optical impression systems presenting with different characteristics were selected for this in vitro study (Table 1): (1) Cerec Bluecam (BL; Dentsply Sirona); (2) Cerec Omnicam (OM; Dentsply Sirona); (3) PlanScan (PL; Planmeca); (4) True Definition (TD; 3M ESPE); and (5) Trios 3 (TR; 3Shape).

Digital Impressions
The three simulated patient situations were scanned using the five selected IOS systems, starting with P1, followed by P2, and then 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) for each model (P1–P3) with each IOS system. All models were first scanned using the three systems that did not require surface preparation: OM, TR, and PL. The models were prepared thereafter using a matting powder (Cerec Optispray, Dentsply Sirona) before scanning with the BL, then prepared with a dusting powder (High Resolution Scanning Spray, 3M ESPE) before use of the TD. The scan data were directly exported from the acquisition unit (OM, BL, TR, PL) or sent for postprocessing (TD) and then exported in STL format. All impressions were made by a single operator (M.D.) after training in the use of all the IOS systems.

Scan File Preparation for Comparisons
The obtained STL data from the 10 scans of each model using the five IOS systems 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 RMS was used to evaluate the compliance of the tested superimposed data.

**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 (Dentsply Sirona)</td>
<td>Powder</td>
<td>Triangulation/spectral images</td>
</tr>
<tr>
<td>Cerec Omnicam (Dentsply Sirona)</td>
<td>None</td>
<td>Triangulation/continuous images</td>
</tr>
<tr>
<td>PlanScan (Planmeca)</td>
<td>None</td>
<td>Triangulation/continuous images</td>
</tr>
<tr>
<td>True Definition (3M ESPE)</td>
<td>Powder</td>
<td>Active wavefront sampling/continuous images</td>
</tr>
<tr>
<td>Trios 3 (3Shape)</td>
<td>None</td>
<td>Confocal microscopy laser/continuous images</td>
</tr>
</tbody>
</table>

Analysis of Accuracy
The trueness (ISO 5725-1) of each IOS system was assessed by comparing the digital impressions to the actual original geometry of the model, meaning that all of the STL data (n = 10) from each tested group (BL, OM, PL, TD, and TR; in P1–P3) were superimposed with the corresponding reference scans made with the laboratory scanner (REF 1–3).

The precision of the IOS systems 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, and TR; in P1–P3) were superimposed among themselves.

Statistical Analyses
Nonparametric distribution was confirmed using Kolmogorov-Smirnov test. All comparisons were therefore performed using Kruskal-Wallis test followed by Dunn-Bonferroni adjusted post hoc test to show homogenous subsets based on rank. The significance level was set at P < .05. Statistical analysis was performed using SPSS statistical software version 22.0 (IBM).

**RESULTS**

Accuracy of the Reference Scanner
The 10 STL data files of the Lego brick scans were superimposed and compared in pairs, resulting in a total of 45 comparisons. The average value for precision over the 45 comparisons was 22.8 ± 17.5 μm.

The average length of the bricks measured on the 10 STL data files was 1.0 ± 3.7 μm larger than the
The purpose of this in vitro study was to evaluate the accuracy (ie, 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 others 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 P1 scenario, TD was significantly better in terms of trueness than all the other tested groups, whereas in the P2 and P3 scenarios, TR achieved better trueness values. On the contrary, PL was found to be inferior to the other systems for both aspects of accuracy in all three clinical 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 TR, which was found to provide the best combination of speed, trueness, and precision for complete-arch scans. These findings are in accordance with the results of the present study. In a recently published study, the accuracy of nine IOS systems was evaluated, and similar trends as in the present study were reported. The trueness and precision of the complete-arch scans made with three of the scanners (TR, TD, and OM) were better than the ones made with the other tested scanners. Similar to the present study, TR presented the best outcomes for both accuracy parameters.

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 μm, 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 so does the interpretation of divergences after superimposition and the 3D comparison. In some studies, 20% of the measured points (outliers) were excluded from the analysis, while in other studies, a trimming of the virtual model with the elimination of artifacts and/or the gingival area was performed before the 3D comparison. 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.

Fig 2 3D comparison of trueness of all IOS systems. (a) P1 (full arch). (b) P2 (anterior gap). (c) P3 (posterior gap).
Additionally, a significant difference was found among 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 the anterior teeth and the buccal surfaces of molars, indicating a slight distortion of the posterior teeth. In the two scenarios with partial edentulism, P2 in the anterior area and P3 in the posterior area, better results were found, which could be explained by the elimination of the areas where 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 to or better than the digital scans of BL, OM, TD, TR, iTero 3D scanner (Invisalign), and Lava COS (3M ESPE), with the digital impression groups of TR and OM reaching the same high-precision levels as conventional impression groups.\textsuperscript{22,23} The results of the present study are in agreement with previous studies reporting values of precision < 90 μm for the TR group in all clinical scenarios—which was significantly better than the other groups—followed by the OM and TD groups.\textsuperscript{22,23}

All of the comparisons in the present in vitro study were undertaken after the digitization of a master model with a laboratory 3D scanner (iScan D104i), which is recommended for high-accuracy scanning.\textsuperscript{19} The validation of the reference scanner used was an imperative precondition to this study, and the value of trueness < 10 μm was consistent with previous reports.\textsuperscript{19,24,25} The revealed accuracy of the reference scanner in this in vitro study enhances the accurate results of all 3D comparisons of the 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, no system 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:

- In situations with anterior or posterior gaps, TR exhibited the highest accuracy, followed by OM and TD.
- In fully dentate situations, TD provided the highest trueness; however, not the highest precision.
- TR provided the highest precision in all three clinical situations.
- PL showed the most inferior accuracy in all three clinical situations.
- None of the tested systems exhibited superior accuracy in all tested clinical situations.

**ACKNOWLEDGMENTS**

The present study was supported by the University of Geneva with the tested scanners. The study was not financially supported by any companies. The authors report no conflicts of interest.
Role of Thin Gingival Phenotype and Inadequate Keratinized Mucosa Width (< 2 mm) as Risk Indicators for Peri-implantitis and Peri-implant Mucositis

There is growing evidence on the impact of thin gingival phenotype (TnP) and inadequate keratinized mucosa width (KMW < 2 mm) around dental implants on peri-implant health. This study investigated the role of TnP and inadequate KMW as risk indicators for peri-implantitis and -mucositis and on dental patient-reported outcomes. A total of 63 patients with 193 implants (mean follow-up of 6.9 ± 3.7 years) were given a clinical and radiographic examination and a questionnaire to assess patient awareness of food impaction and pain/discomfort. Chi-square tests and regression analysis for clustered data were used to compare outcomes. Implants with TnP had a statistically higher prevalence of peri-implantitis (27.1% vs 11.3%; PR: 3.32, 95% CI: 1.64–6.72; P = .001) peri-implant mucositis (42.7% vs 33%; PR: 1.8, 95% CI: 1.1–2.9; P = .016), and pain/discomfort during oral hygiene (25% vs 5%; PR: 3.7, 95% CI: 1.06–12.96; P = 0.044) than thick phenotype. Implants with inadequate KMW had a statistically higher prevalence of peri-implantitis (24.1% vs 17%; PR: 1.87, 95% CI: 1.07–3.25; P = .027) and peri-implant mucositis (46.6% vs 34.4%; PR: 1.53, 95% CI: 1–2.33; P = 0.05) and pain/discomfort during oral hygiene (28% vs 10%; PR: 2.37, 95% CI: 1–5.1; P = .027) than with adequate KMW. TnP was strongly associated with inadequate KMW (PR = 3.18, 95% CI: 1.69–6.04; P < .001). Conclusion: TnP and inadequate KMW (< 2 mm) may be significant risk indicators for peri-implant disease and pain/discomfort during brushing.

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