Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience

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Because computer-aided design and computer-aided manufacturing (CAD-CAM) technology was introduced to dentistry in the early 1980s, the in-office fabrication of inlays, onlays, crowns, and fixed partial dentures, as well as implant surgical guides and immediate interim implant crowns have been possible. 1-9 Intraoral scanners have enabled the acquisition of data directly from the oral cavity. 6 Studies of the accuracy of intraoral scanners have been performed with individual abutments, 7-11 CAD-CAM restorations, 12-14 and quadrant- and complete-arch scans. 15-27 Among those studies, Ender et al. 15 compared the trueness and precision of conventional impressions versus CEREC Bluecam and LAVA COS optical impressions from a complete-arch model and reported similar accuracy for digital and conventional methods. Patzelt et al. 20 digitized a model with 14 prepared abutments with an industrial scanner and 4 intraoral scanners and reported that, except for 1, system, all intraoral scanning systems showed comparable levels of trueness and precision. Ender et al. 21 compared the accuracy of 4 conventional with that of 4 digital systems and showed similar accuracy for both groups. The single-image based system required repeated learning sessions for effective clinical application. The newer system offered better trueness and precision and was less likely to be influenced by the length of clinical career or the region being scanned. (J Prosthet Dent 2018;119:225-232)
**Clinical Implications**

Variations in the trueness of an intraoral scanner depend on the experience of the practitioner. This is an important clinical consideration before using digital impression making as an alternative to traditional impression making.

complete-arch impressions and concluded that the intraoral scanning systems showed higher local deviations and were no more accurate than conventional impressions. Renne et al.24 evaluated the accuracy of 6 intraoral scanning systems in both quadrant and complete arches and found that the orders of trueness and precision of the systems were different for the 2 test arrangements. However, because most of these studies were based on models, they have limited application for clinical practice. Ender et al.25 recently conducted an in vivo study and compared the precision of conventional with digital methods for complete-arch impressions. They concluded that the digital technique yielded higher local deviations within the complete-arch cast; however, they produced equal and higher precision than irreversible hydrocolloid materials. In these studies, the participants were already experienced with optical impression systems in order to reduce the risk of operator bias. As a result, how operator experience influences data accuracy could not be evaluated.

Birnbaum and Aaronson28 stated that users of digital intraoral scanners would require time and education to develop new skills in order to provide a fast and convenient restoration with the best fit. Typically, learning curves in dental students show a trend of initial enhancement of performance ability as knowledge or skills are accumulated through repeated practice; without the addition of new skills, the curve is slowed after a certain time, despite additional practice.28,29 In the field of general medicine, many studies have investigated the learning curve of the system users when new technologies are introduced.30-34 However, few studies of the learning curve in dentistry have been done.35-38 The enhancement of skill with a certain device or clinical method can reduce chair time and increase treatment quality. Recently, studies have reported the scan time, preference, and accuracy of digital and conventional impression methods,24,39,40 but the present authors are unaware of studies confirming the level of improvement in proficiency and data accuracy as a result of repeated intraoral scanning.

In this study, we investigated the precision and trueness of 2 digital intraoral scanners with different scanning systems after repeated scanning by clinically experienced dental hygienists who scanned the complete arch of the oral cavity. The impact of clinical experience and scanned region on the trueness of the scanned images was also evaluated. The null hypothesis was that the increase in skill from repeated scanning practice would not influence the accuracy of optical impression data.

**MATERIAL AND METHODS**

This study was approved by the institutional review board at Ewha Womans University Medical Center Mokdong Hospital. The selection criteria for the dental hygienist participants were as follows: clinical experience of 3 to 5 years (short-career group) or more than 6 years (long-career group) in the dental field; a clear understanding of the purpose of the study; voluntary consent; and ability to carry out a 4-day experience course. The 4 test individuals who took part in this study had Angle class 1 occlusion characterized by mild crowding (<3 mm). A total of 24 dental hygienists applied for this study. Four of them did not attend the appointment after 1 or 2 visits and were counted as dropouts as they could not complete the experience process. A total of 20 hygienists were thus included, 12 of whom belonged to the short-career group and 8 to the long-career group. The mean age of each participant group was 27.9 ±0.8 years of age for the short-career group and 31.1 ±1.7 years of age for the long-career group. All participants were female and had no experience with optical scanning.

The scheduling of the participants’ first visits and the test individuals’ distribution for scanning systems were conducted based on a list which was prefabricated by a third person. At the first visit, 2 hygienists were distributed to 2 impression systems by simple randomization.

The iTero (Align Technology) and Trios (3Shape) intraoral scanners were used according to the manufacturer’s instructions. The iTero uses a red laser beam and parallel confocal imaging technology to capture up to 100 000 points of laser light with an accuracy of <20 μm, according to the manufacturer’s data. The Trios scanner is operated on the confocal principle, with the video bitrate image capturing method based on the real-time rendering technique.

The participants scanned at the dental clinic for 4 consecutive days. To investigate the difference in precision and trueness of the 2 intraoral scanners, the participants scanned the maxillary and mandibular arch of a single test individual 10 times each using 1 assigned scanner as follows. On the first day, either of the 2 scanners (iTero and Trios) and 1 test individual were assigned. After receiving training in the theory and practice of the assigned scanner, the participants scanned the dental arch of the assigned individual twice. On the second and third days, the dental arch of the same individual was scanned 3 times each, and on the fourth
day, the experiment was concluded after rescanning the same individual twice.

To create reference images for the assessment of trueness, impressions of the maxillary and mandibular arch of the 4 test individuals were made with a polyether impression material (Soft Monophase; 3M ESPE), and an intaglio scan was performed using a calibrated desktop scanner (7Series; Dental Wings Inc). The scanning strategy was standardized by instructing the participants to follow the manufacturer’s recommendation. In the iTero group, parts of the dental arch were captured and superimposed to complete an image, with overlapping sufficient to ensure that the image stitching process would not generate errors. The scanning direction was to start from the left of the mandible, proceed clockwise across the complete arch one quadrant at a time, and follow by scanning for bilateral occlusion. The automatic capture function was used for continuous image acquisition. In the Trios group, the scanning direction was the same as that followed by the iTero group. For smooth recognition of the scanning area, the occlusal surface was recommended as the starting point for scanning.

All images from 20 participants were transformed to the standard tessellation language (STL) file format. For the measurement of precision, the images acquired from 10 scans by each participant with the assigned intraoral scanner were paired, and the mean and maximum deviations of these 45 pairs were calculated \((n=10C_2=45)\). To compare trueness, the reference image was superimposed one by one on a total of 10 images acquired by participants in the order of scanning. Subsequently, the differences between polygons were compared, and the variations in trueness with repeated experience were assessed \((n=10)\). After images were initially superimposed with an auto align command through the scanner inspection software (Geomagic Verify v4.1.0.0; 3D Systems Inc), irregular parts of the gingiva, including the buccal vestibule, beyond 2 to 3 mm apical from the gingival margin were cut out to make the fine registration more accurate. Trimmed images were registered again using a best-fit align command to match the more than 60,000 points composing each image. Deviations between triangular polygons formed by the points composing 2 superimposed images were computed and the distance data of all superimpositions were summarized and imported into a statistical program.

Collected data were analyzed using a statistical software (IBM SPSS Statistics v20.0; IBM Corp). To determine the differences in the deviations according to the scanner, the independent 2-sample \(t\) test was conducted to examine the significance of the precision data. For comparisons of trueness according to repeated experience, the repeated measures ANOVA was used to test for differences between the scanners, clinical experience of the participants, and the scanning region within the same scanner group. The significance of time-dependent changes and the interaction between the scanner group and time variables were examined by within-subject tests. Differences between the scanner groups were examined by between-subject tests. The significance of the 10 consecutive scans and 4 visits in the scanner group and the difference between the scanner groups at each time point were examined by post hoc Bonferroni test \((\alpha=.05\) for all tests).

### RESULTS

Results of the independent 2-sample \(t\) test showed that the precision of the participants’ skill in the Trios group was significantly better than that of the iTero group \((P<.001)\) (Table 1; Fig. 1).

Deviations between the scanned images of the dental arch and the reference image used to examine trends in the trueness of 10 consecutive scans are shown in Table 2. Significant differences in trueness were found between the scanners and with repeated experience \((P=.005\) and \(P=.047)\). The difference between the scanners for each scan was statistically significant, with the high mean trueness generally shown in the iTero group. Within the iTero group, the results of the repeated measures ANOVA showed that there were differences

### Table 1. Precision of scan images obtained with iTero and Trios (\(\mu m\))

<table>
<thead>
<tr>
<th>Variable</th>
<th>iTero ((n=12))</th>
<th>Trios ((n=8))</th>
<th>(F)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>60.5 ±32.9</td>
<td>52.3 ±45.5</td>
<td>4.414</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Maximum</td>
<td>649.6 ±239.1</td>
<td>451.1 ±255.1</td>
<td>16.792</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Statistically significant at \(P<.05\). Precision measured by polygon deviation between 2 of 10 images, which totals 45 pairs for each participant.
between the first and second scans, and the sixth, seventh, eighth, ninth, and tenth scans, with a general tendency for improved trueness with repeated practice ($P=.041$). No similar statistically significant trend change was found in the Trios group ($P=.454$) (Fig. 2). Examination of the changes in trends in trueness for each of the 4 daily visits also revealed significant differences between the scanners and the visits (both, $P=.006$) (Table 1). In the iTero group, the trend changes in trueness were statistically significant ($P=.001$) and generally tended to show improvement. No statistically significant differences were found in the trends for each scanning visit in the Trios group ($P=.491$).

Changes in trends of trueness measured at the 4 scanning visits according to clinical experience are shown in Table 3. Significant differences were found between the 2 clinical experience subgroups using the iTero scanner with repeated experience ($P=.001$). The short-career subgroup showed a statistically significant difference between the first 3 days and the fourth day, while the long-career subgroup showed a statistically significant difference between the first day and the last 3 days ($P=.014$ and $P=.012$). The mean deviation also decreased in both iTero subgroups. In the Trios group, no statistically significant differences were observed between the 2 clinical experience subgroups (Fig. 3).

Changes in trends of trueness measured at the 4 scanning visits according to the scanned regions of the maxillary and mandibular arch are shown in Table 4. At each of the 4 scanning visits in the iTero group, a difference was found between the maxillary and mandibular arch, with better trueness in the maxillary arch with the repeated experience ($P=.002$). The trueness of the maxillary arch was improved with repeated scanning visits ($P=.046$). Within the Trios group, the difference between the maxillary and mandibular arch was not statistically significant, nor was the change in trueness according to each scanning visit (Fig. 4).

**DISCUSSION**

In this study, the null hypothesis was rejected because the trueness of optical impression data showed significant improvement with repeated scanning practice in the iTero group. The clinical experience and the scanned region affected the trueness of the scanned images of the iTero digital intraoral scanner but not that of the Trios system.

This study was different from other similar studies in several aspects. First, this study was conducted in the oral cavity environment rather than on a model. Second, the relationship between the skill in scanning and the trueness of images was assessed with an experience curve. In other studies, the participants already had intraoral scanner experience, and thus the skill of the users could not be ruled out as a factor affecting the accuracy of the scanner. Last, the reference images in this study were made with impression scanning. Although model scanning is typically performed to obtain the reference image, an error is generated because

### Table 2. Trueness of 10 consecutive images obtained with iTero and Trios ($\mu m$)

<table>
<thead>
<tr>
<th>Scanner</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
<th>T8</th>
<th>T9</th>
<th>T10</th>
<th>F (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>iTero (n=12)</td>
<td>99.8 ±19.7</td>
<td>98.8 ±18.6</td>
<td>93.0 ±21.7</td>
<td>95.3 ±18.8</td>
<td>96.0 ±27.0</td>
<td>90.2 ±19.8</td>
<td>91.9 ±24.0</td>
<td>91.5 ±22.7</td>
<td>87.7 ±16.9</td>
<td>87.5 ±23.9</td>
<td>1.996 (.041)</td>
</tr>
<tr>
<td>Trios (n=8)</td>
<td>80.9 ±15.7</td>
<td>84.3 ±16.6</td>
<td>79.3 ±7.9</td>
<td>78.8 ±10.8</td>
<td>83.2 ±13.3</td>
<td>75.3 ±9.4</td>
<td>80.0 ±12.5</td>
<td>79.9 ±10.6</td>
<td>81.2 ±11.1</td>
<td>79.8 ±13.6</td>
<td>.986 (.454)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>3.205</td>
</tr>
<tr>
<td>Visit 2</td>
<td>2.519</td>
</tr>
<tr>
<td>Visit 3</td>
<td>2.388</td>
</tr>
<tr>
<td>Visit 4</td>
<td>3.188</td>
</tr>
</tbody>
</table>

**Figure 2.** Trueness of 10 consecutive images obtained with iTero and Trios.
of the expansion of the gypsum. DeLong et al. measured the data accuracy after using a tabletop scanner to scan both the poured stone cast and the impression body from a steel standard model. They reported that the impression scan (13 ±3 mm) was nearly twice as accurate as the cast scan (24 ±2 mm).

As the scope of studies on digital intraoral scanners has expanded, various methods of verifying the trueness of the digital scan image have been used. van der Meer et al. used a cylinder to evaluate the errors in distance and angle, and Grünheid et al. measured the distance by creating a reference ball in the model. The precision of the iTero measured in this study was 60.5 mm and slightly higher than the 50-mm figure reported by Flügge et al. and the 36.4-mm figure reported by Ender and Mehl. This seems to be caused by the difference between a clinical and in vitro study. Compared with the in vivo precision of the iTero and Trios systems reported by Ender et al., the trueness in this study, acquired at the tenth practice where scanning experience had been accumulated, was still high. This could be explained by the fact that 2 dentists, already expert in operating the intraoral scanner, participated in the study by Ender and Mehl, whereas the hygienists in this study did not have any experience and came to learn. Unlike Ender et al., who superimposed 2 images among data sets of the same group and measured deviations to assess the precision, we superimposed scanned images onto the reference image to assess the trends in trueness. However, errors in the desktop scanner used to acquire the impression scan during such a process cannot be ruled out.

When the deviation patterns were evaluated from the color map, the iTero tended to produce images that were bigger in general and had higher deviations in the molar region. Ender and Mehl suggested that this pattern in the iTero could be attributed to single-image stitching. In addition, the iTero scans the quadrant arch separately, and the image stitching is completed by collecting right and left quadrant images at the anterior region. The range of the deviations was smaller than for the iTero. Ender et al. reported in their in vivo study that 1 quadrant began to distort the distal-to-canine region in the video-based system, whereas local deviation was shown with increasing deformation in the distal direction in the single image-based system. For the quantified evaluation, the deviation between reference and intraoral scan data at the buccal and palatal reference points on second molars was measured in this study. From this linear measurement, the mean buccolingual displacement in the iTero group and Trios group (Fig. 5).

To see the trends in trueness according to the skill of the scanner user, the images acquired from the 10 scans were sequentially superimposed onto the reference image in the order of scanning. While the trueness values improved in both scanner groups, only the change in the iTero group was significant. These results may indicate
that there was a learning effect due to the repeated scanning. In contrast, while the Trios group did not show a significant difference in trueness over 10 scans, overall it offered better trueness and precision than the iTero group. From the complete-arch in vivo study by Ender et al, the precision of older systems like iTero was reported to be lower than with newer systems like Trios. Given these results, the Trios appears to require less training time than the iTero, making it easier to use in clinical practice. However, the experience accumulated in the process of adapting to the machine through repeated experience might effect a change in the trueness potential of the iTero.

The length of clinical experience influenced the effect of repeated experience that was evident only in the iTero group. The long-career group showed a significantly reduced deviations in the first scanning on the second day and a relatively stable curve up to the final scanning. However, the short-career group showed a trend in trueness that consistently improved with practice, without a sharp decrease in deviations. Although this was not analyzed statistically, it may be that the long-career group had become skilled relatively faster than the short-career group. In studies of actual patients rather than models, clinical experience in terms of the ability to react to the patients’ movements, saliva or tongue, which might interfere with the scanning, must be considered as a factor affecting trueness. The ability to react to the patient-specific factors is stronger in the long-career group, and it seems that this aspect was expressed in the system with the higher level of difficulty. On the contrary, depending on the kind of system, the experienced operator also can produce less accurate digital impressions if he or she rotates the scanner frequently to capture a wider area.

Comparing the scanned regions, a statistically significant difference was also found between the maxillary and mandibular arch in the iTero group. When the scanning experience of the participants had accumulated the most, trueness was better in the maxillary arch than the mandibular arch. Conversely, Flügge et al reported better trueness for the mandibular arch, whereas Ender reported that the deviations were larger in the maxillary arch because the labial surface of the maxillary anterior teeth had to be approached at more difficult angles. The different outcomes produced with iTero in this study might have been due to the participants’ reported difficulty with the approach of the tip to the lingual surface of the mandibular anterior teeth; here the size of the arch was relatively smaller than that of the maxillary arch because of the volume of the wand.

The shape of an experience curve that graphically represents the phenomenon of learning is diverse, but normally there comes a point where the accumulation of knowledge and skills obtained through experience reveals learner competence. While the results generally showed a declining trend in the curve of the graph, the learners in this study performed too few scans to determine the point where the curve might have become gradual. The participants only worked with one of the
scanning systems, and the test was not repeated by switching the participants and the systems. As a result, a risk of selection bias is possible. In addition, our attempt to investigate the influence of the user’s clinical experience on scanner trueness by dividing the participants into long and short-career subgroups was hampered by the participants’ overall inexperience with digital intraoral scanners, which are currently not widely available. Future studies should refine the skill level of the selected participants and gather a larger dataset of user experience opportunities to find the point at which learners become competent with digital intraoral scanners.

**CONCLUSIONS**

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

1. Repeated experience, clinical experience, and the scanned region all affected the trueness of the scanned images of the single-image-based system. Consequently, users require repeated experience opportunities for effective clinical application.
2. The video-based system offered better trueness and precision and was less likely to be influenced by the length of clinical career and the region being scanned.
3. Although clinicians cannot afford to introduce every latest device, newer versions seem to be more accurate and could more easily be applied to clinical practice.

**REFERENCES**


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