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RESEARCH AND EDUCATION

Influence of operator experience, scanner type, and scan size on 3D scans

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ABSTRACT

Statement of problem. Intraoral scanners (IOSs) have some inherent distortions caused by optical and/or software imperfections. However, how other factors such as operator experience, scan time, scanner type, and scan size influence scan accuracy is not clear.

Purpose. The purpose of this in vitro study was to evaluate the trueness and precision of scans performed by 3 professionals with different levels of experience by using 2 IOSs.

Material and methods. Three operators with low, medium, and high levels of experience scanned a master model 10 times by using 2 IOSs (CEREC Omnicam; Dentsply Sirona and TRIOS 3; 3Shape), resulting in 10 standard tessellation language files for each group (N=60). Each standard tessellation language file was divided into 2 areas (prepared teeth and complete arch). Precision was evaluated by comparing the 10 scans from each examiner for each system. Trueness was evaluated by comparing each scan file with a reference scan obtained from a laboratory scanner (D2000; 3Shape). A 3D analysis software program (Geomagic Control; 3D Systems) was used to perform all the comparisons and superimpositions. The 3-way ANOVA test followed by the Tukey HSD test were used to assess precision and trueness. The 2-way ANOVA followed by the Tukey HSD test was used to assess scan time. The Pearson correlation test was performed between scan time and trueness for both scanners. An additional correlation was performed between scan time and number of images, as well as between number of images and trueness for the TRIOS 3.

Results. Statistically significant influences of operator ($P<.001$), scanner ($P<.001$), scan size ($P<.001$), operator and scan size ($P<.001$), and scanner and scan size ($P<.001$) were observed. The TRIOS 3 group reported higher precision than the CEREC Omnicam group for complete-arch scans ($P<.001$), although no difference was observed for scans of the prepared tooth. Medium- ($P=.002$) and low-experience operators ($P<.001$) reported lower precision for complete-arch scans performed with CEREC Omnicam when compared with TRIOS 3. The low-experience operator reported significantly worse results for complete-arch scans in comparison with the medium- ($P=.008$ and $P<.001$) and high-experience operators ($P<.001$ and $P=.001$), by using TRIOS 3 and CEREC Omnicam, respectively. Medium- and high-experience operators reported similar results among themselves. The CEREC Omnicam scanner reported lower trueness for complete-arch scans when compared with the prepared tooth ($P<.001$); for TRIOS 3, a difference was only observed for the low-experience operator when compared with the high-experience operator ($P<.001$). The CEREC Omnicam reported lower trueness than the TRIOS 3, except for the medium-experience operator with the prepared tooth scan. Comparing the trueness between operators and considering the same scanner and scan size, all groups were similar. The low-experience operator had a longer scanning time than the medium- and high-experience operators. For TRIOS 3, the low-experience operator obtained the highest number of images during each scan.

Conclusions. The accuracy of intraoral scans was influenced by operator experience, type of IOSs, and scan size. More experienced operators and smaller scan sizes made for more accurate scans. In addition, more experienced operators made faster scans, and the TRIOS 3 was more accurate than the CEREC Omnicam for complete-arch scans. (J Prosthet Dent 2020;■:■-■)

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Clinical Implications

Operator experience and scanner type play an important role in accuracy and scanning time. Moreover, larger scans (complete arch versus partial arch) tend to be less accurate, especially when associated with low-experience operators and should be limited when not required. As an accurate scan is essential for the long-term success of restorative treatment, understanding the influence of the scan type, size, and operator experience on the scan quality is essential.

Digital technology in dentistry has evolved rapidly since the introduction of computer-aided imaging, computer-aided design, and computer-aided manufacturing (CAI, CAD, and CAM) to oral rehabilitation, allowing the analysis, planning, and fabrication of dental crowns and veneers, implant frameworks, 3D printed models, dental aligners, and surgical guides.[1] Impressions or scans of the oral cavity represent an important step, and intraoral scanners (IOSs) enable direct data acquisition without the need for impression materials or devices.[1] In addition, the digital workflow allows 3D previsualization of hard and soft-tissues, is able to avoid distortions from impression materials and stone casts, can reduce laboratory and clinical time, and increases patient acceptance and comfort, providing a cost-effective and time-effective workflow.[2-6] If a physical cast is necessary, it can be fabricated by prototyping (3D printing or milling) of the intraoral scan data.[7-11]

Digital scans have disadvantages. Besides the costs involved, scanner accuracy plays a major role in the definitive result. Accuracy is determined by trueness and precision (ISO 5725-1).[12-21] Trueness describes how far the measurement deviates from the actual dimensions of the measured object. A high trueness delivers a result that is close or equal to the actual dimensions of the measured object. Precision describes how close repeated measurements are to each other. The higher the precision, the more predictable is the measurement.[22] In addition, a few studies have reported the importance of the learning curve,[10,11] and a variation in the trueness of an IOS could be associated with the experience of the practitioner.[3,10,23] Another important concern is related to the number of images made. This will increase when scanning larger areas and/or taking longer to scan, as with a less experienced operator, as each new image is aligned to the previous ones by the software program, thereby introducing inherent errors.[19]

Considering the lack of studies assessing the impact of operator experience on the intraoral scanning process, the purpose of this in vitro study was to evaluate the 2 components of the accuracy (trueness and precision) of 2 intraoral scanning systems operated by 3 professionals with different levels of experience (low, medium, and high) and with 2 scan sizes (prepared tooth and complete arch). In addition, the present study assessed the influence of the operator experience on the scan time and file size, as well as their relationship with accuracy.

The null hypotheses tested were that no differences in accuracy would be found between the different scanners regardless of the operator; that no differences in accuracy would be found between the different scanners regardless of the scan size; that no differences in scan time would be found regardless of the operator and scanner; and that no correlation would be found between scan time and trueness.

Table 1. Scanners evaluated

Scanners	Manufacturer	Scanner Technology	Acquisition	Necessity of Coating
CEREC Omnicam	Dentsply Sirona	Active triangulation	Color Video	Free
TRIOS 3	3Shape A/S	Ultrafast Optical sectioning	Color Video	Free
D2000	3Shape A/S	Multiline scanning	Color Video	Free

MATERIAL AND METHODS

The present study followed a 3×2×2 factorial design having as main study factors the operator experience at 3 levels: low, medium, and high experience; IOSs at 2 levels: Omnicam (CEREC Omnicam v4.5.1; Dentsply Sirona) and TRIOS 3 (TRIOS 3 Dental Desktop v1.6.4.1; 3Shape); and scan size at 2 levels: complete arch and single prepared tooth, having as response variables the precision and trueness assessed by using a 3D analysis software program Geomagic Control (3D Systems). In addition, the scanning time (for both scanners) and number of images (for TRIOS 3) were assessed as secondary outcomes.

The experimental unit was composed of 10 scans in standard tessellation language (STL) files for each group (N=60), which were compared among themselves (precision) or with a master scan of the same model (trueness) obtained by using a high-precision laboratory scanner (D2000 Dental Desktop v1.6.4.1; 3Shape) (Table 1).

All the scans were obtained based on a 3D printed typodont (master maxillary model) (Fig. 1) with 2 prepared teeth (first maxillary right premolar and first maxillary right molar) and 3 implants (from first maxillary left premolar to first maxillary left molar) to receive a fixed dental prosthesis. Before image acquisition, CEREC Omnicam, TRIOS 3, and D2000 scanners were calibrated following the calibration guidelines of the respective manufacturers.

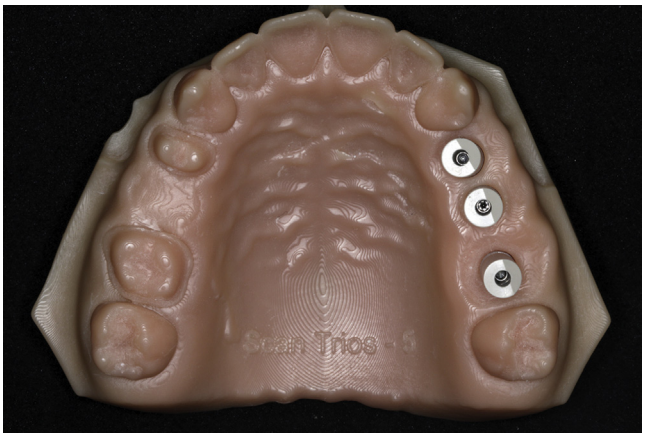

Figure 1. Master model.

Three dentists with different levels of experience (high experience, medium experience, or low experience) scanned the master model 10 times for each of the 2 tested scanners. All 3 evaluators had the same training for the IOS. The high-experience operator, in addition to the training, had used the scanner for more than 2 years with at least 3 scans a day. The medium-experience operator, in addition to the training had used the scanner for more than 1 year with at least 1 scan a week. The low-experience operator had only the training experience. The scanning was divided into 3 steps: scanning the occlusal surface, scanning the buccal surface by inclining the scanner wand toward the buccal surface while moving the reference model, and scanning the lingual surface by inclining the scanner wand toward the lingual surface and scanning the lingual surface.[3] Each scan was evaluated in 2 areas: prepared teeth and complete arch by using analysis software (Geomagic Control; 3D Systems, Inc). A researcher (T.Q.) recorded the scan time by using a digital stopwatch.

All obtained files were exported to STL by using the respective manufacturers software program (by using the highest quality available) and imported into the 3D analysis software program. For precision, all acquired images from each of the groups (CEREC Omnicam and TRIOS 3) were paired and superimposed (in a total of 45 analyses for each group) by using a best fit algorithm tool, which automatically aligned both reference and test model files, allowing subsequent objective measurements of variances across the 3D models.[23] For each pair of scans, irregular parts of the gingiva, including the buccal vestibule (beyond 2 to 3 mm apical of the gingival margin), were cut out to make the refined alignment (second best fit alignment) more accurate. Each superimposed file was analyzed with the 3D comparison tool, which assessed the average maximum and minimum deviation (in μm) and the standard deviation between the scanned files. For trueness, the same protocol was followed, but each of the 10 scans for each group was compared with the master scan file (D2000). Additionally, the TRIOS 3 scanner system recorded the number of images per scan, which was also evaluated.

Data were evaluated for normality by using the Shapiro-Wilks test. The 3-way ANOVA test followed by the Tukey test were used to assess precision and trueness. The 2-way ANOVA followed by the Tukey test were used to assess scan time. The Pearson correlation test was performed between scan time and trueness for both scanners. An additional correlation was performed between scan time and number of images, as well as between number of images and trueness for TRIOS 3 (α=.05 for all tests).

RESULTS

Precision was influenced by operator (P<.001), scanner (P <.001), scan size (P <.001), scanner and scan size (P<.001), and operator and scan size (P<.001). All operators reported lower precision (higher values) for complete-arch scans when compared with prepared tooth scans, except for the medium-experience operator by using TRIOS 3. Considering the complete-arch scans, the medium- and low-experience operators reported lower precision with the CEREC Omnicam when compared with the TRIOS 3 scanner. In addition, the low-experience operator reported significantly worse results for complete arch scans with both scanners when compared with the medium- and high-experience operators, who had similar results. The highest precision (lowest values) was observed for all prepared tooth scans performed with TRIOS 3. The lowest precision was observed for the complete-arch scan performed by the low-experience operator by using the CEREC Omnicam scanner (Table 2).

Analysis of trueness found the influence of scanner (P<.001), scan size (P<.001), scanner and scan size (P=.004) and operator, scanner, and scan size (P=.023). All operators reported similar results considering the same scanner and scan size. All complete-arch scans performed with the CEREC Omnicam presented lower trueness (higher deviation) than the tooth preparation scans. For the TRIOS 3, this was observed only for the low-experience operator. All operators had lower trueness with the CEREC Omnicam when compared with the TRIOS 3 scanner, except the medium-experience operator with the prepared tooth scan. The highest trueness (lowest values) was observed for the prepared tooth scans with the TRIOS 3. The lowest trueness was observed for the complete-arch scans with the CEREC Omnicam scanner (Table 3).

Operator (P<.001) and scanner (P=.025) played an important role in scan time. The low-experience operator took significantly more time to perform the scans when compared with the medium- and high-experience

Table 2. Precision (mean ±standard deviation) considering different scanners, scan size, and operators

Scanner×Arch Size	Medium Experience (μm)	High Experience (μm)	Low Experience (μm)
CEREC Omnicam and Complete Arch	0.12 ±0.06 Aa1	0.10 ±0.029 Aa1	0.16 ±0.12 Ab1
CEREC Omnicam and prepared arch	0.04 ±0.05 Aa2	0.04 ±0.020 Aa2	0.04 ±0.02 Aa2
TRIOS 3 and Complete Arch	0.05 ±0.04 Ba1	0.07 ±0.040 Aa1	0.11 ±0.06 Bb1
TRIOS 3 and prepared arch	0.03 ±0.02 Aa1	0.03 ±0.04 Aa2	0.03 ±0.02 Aa2

Uppercase letters indicate difference between scanners considering same operator (column) and scan size. Lowercase letters indicate difference among operators considering same scanner and scan size (difference between columns). Numbers indicate difference between scan size considering same operator and scanner.

Table 3. Trueness (mean ±standard deviation considering different scanners, scan size, and operators

Scanner×Arch Size	Medium Experience (μm)	High Experience (μm)	Low Experience (μm)
CEREC Omnicam and Complete Arch	0.14 ±0.02 Aa1	0.12 ±0.01 Aa1	0.12 ±0.03 Aa1
CEREC Omnicam and prepared arch	0.06 ±0.01 Aa2	0.07 ±0.04 Aa2	0.08 ±0.04 Aa2
TRIOS 3 and Complete Arch	0.06 ±0.01 Ba1	0.06 ±0.003 Ba1	0.07 ±0.005 Ba1
TRIOS 3 and prepared arch	0.03 ±0.01 Aa1	0.03 ±0.02 Ba1	0.03 ±0.02 Ba2

Uppercase letters indicate difference between scanners considering same operator (column) and scan size. Lowercase letters indicate difference among operators considering same scanner and scan size (difference between columns). Numbers indicate difference between scan size considering same operator and scanner.

operators. Although the TRIOS 3 resulted in faster scans than the CEREC Omnicam ($P<.025$), no significant differences were observed between scanners with the same operator ($P=.322$) (Table 4). The Pearson correlation found very weak to weak correlation between time and trueness for both scanners (0.342—TRIOS 3 and 0.153—CEREC Omnicam). For TRIOS 3, there was a strong correlation between scan time and the number of images (0.729), but a weak correlation between the number of images and trueness (0.202).

DISCUSSION

Different factors play important roles in determining the success of an indirect restoration. With the development of digital technologies, IOSs are able to avoid distortions from impression materials, as well as save time and space from impression processing and transportation.[2-6] Nevertheless, digital scanners can introduce inherent errors of alignment within the software program, and the effects of the scan size, scan type, scanner time, and operator experience on the definitive results is unclear.[1,3,10,11,19]

Based on the results of the present study, the first 3 null hypotheses (that no differences in accuracy would be found between the different scanners regardless of the operator; that no differences in accuracy would be found between the different scanners regardless of the scan size; and that no differences in scan time would be found regardless of the operator and scanner) were rejected. The fourth null hypothesis (that no correlation would be found between scan time and trueness) was accepted.

Accuracy is determined by precision and trueness.[12-21] Precision describes how close repeated measurements are to each other and was influenced by the operator experience ($P<.001$), scanner ($P<.001$), and scan size ($P<.001$), as well as by the interaction between operator and scan size ($P<.001$). Complete-arch scans had lower precision than tooth scans, probably because of the larger area involved; within this context, more experienced operators (medium and high experience) reported higher precision than low-experience operators, especially with TRIOS 3. These results evidence the importance of operator experience. However, the average 6-μm lower precision when compared with more experienced operators is probably not clinically relevant. The results of precision for the present study are consistent with those of previous reports,[3,14,15] except for the results of CEREC Omnicam for complete arches (which is not an indication of the scanner) and TRIOS 3 for the complete arch scanned by the low-experience operator (which might be explained by the use of experienced operators in previous studies).

Considering trueness, the increase in the scan area resulted in lower trueness for all groups, except medium and high experience by using TRIOS 3, indicating that the experience of the operator can play an important role. Considering the same scan size, TRIOS 3 reported higher trueness than CEREC Ominicam for all groups, except the medium experience operator for the prepared tooth scan, which indicated that a medium-experienced operator could obtain similar results with both scanners and supported the use of the CEREC Omnicam as a chairside scanner for single and short-span fixed dental prostheses. Nevertheless, with the same scanner and scan size, all operators obtained similar trueness, indicating that even the low-experience operator can achieve adequate results. Thus, it seems that precision (variation of points) depended more on the experience of the operator, although the differences may not be clinically significant. The tendency of higher trueness (lower values) for operators with longer experience was also observed previously, although only in the short term.[11]

As expected, the learning curve and level of experience played an important role in the scan time for both scanners, with the low-experience operator taking significantly longer times when compared with the medium- and high-experience operators. Such results are consistent with those of a previous study.[10] Moreover, although the TRIOS 3 tends to be faster than the CEREC

Table 4. Scanning time and number of images considering operator and scanner

Operator×Scanner	Scanning Time (sec) (Mean)	Number of Images (Mean)
Medium experience and TRIOS 3	186.22 A	1720
High experience and TRIOS 3	189.88 A	2046
High experience and CEREC Omnicam	191.88 A	-
Medium experience and CEREC Omnicam	212.88 AB	-
Low experience and TRIOS 3	242.77 BC	2405
Low experience and CEREC Omnicam	260.66 C	-

Different letters indicate statistically significant difference between groups ($P<.05$).

Omnicam, with the same scan size and operator, both scanners performed similarly. Nevertheless, the longer postprocessing time for the CEREC Omnicam scanner could be an important factor in daily practice.

Correlations between time and trueness for both scanners were low, as well as between the number of images and trueness for TRIOS 3. This might indicate that the scan technique and movement play a more important role than the time and number of images by itself. Such results are supported by the increased differences with complete-arch scans, especially for the low-experience operator.

The CEREC Omnicam is a powder-free, color video speed scanning system which uses active triangulation and emits white light to measure surfaces.[20] It was designed as a chairside solution for single unit and fixed partial dentures in a single visit when a milling machine is also available. The TRIOS 3 is based on video technology (based on confocal microscopy) that captures the anatomy and color of the oral tissues with a broad focal depth camera.[7,9,20] It was designed mostly to send intraoral scans to laboratories for all prostheses, although it can also be used with a chairside milling machine.

Evaluation of the accuracy of digital scans is treated differently and has been reported in the literature to be accurately analyzed with sophisticated 3D software programs.[1,3,6,11] The software program used in the present study relied on best-fit mathematical algorithms to overlay a digital scan and a digital master file to objectively measure variances across the entire experimental model in relation to the master.[7,19-21]

Trueness was based on the comparison with a master model scan performed with the laboratory scanner, which acquires the image by using built-in cameras with 5 megapixels for texture mapping and features multiline technology, resulting in precision ≤20 μm (ISO 12836).[24]

This study evaluated scans of a typodont performed extraorally, which reduced some differences because it is more complicated to perform intraoral scans in patients. Nevertheless, the present results reported the importance and the impact of the scan size, scanner type, and operator experience on the accuracy of digital scans. Future studies should research the influence of the scan size, scanners, and operator experience on the accuracy of scans performed intraorally.

CONCLUSIONS

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

1. The accuracy of intraoral scans was influenced by operator experience, type of IOS, and scan size.
2. More experienced operators and smaller scan sizes contribute to more accurate and faster scans.
3. The TRIOS 3 was more accurate than the CEREC Omnicam for complete-arch scans.

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