Assessment of the accuracy and reliability of new 3-dimensional scanning devices

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Introduction: The primary objective of this study was to assess the accuracy and the reliability of the SureSmile OraScanner (Orametrix, Richardson, Tex) by comparing it with other desktop 3-dimensional scanners: VIVID910 (Konica Minolta, Tokyo, Japan) and R700 (3Shape, Copenhagen, Denmark). A laser-based scanner, the SLP250 Laser Probe (Laser Design, Detroit, Mich), served as the gold standard. Methods: Five sets of dental casts were used. First, the accuracy of each scanner was studied by comparing the 3-dimensional models created by OraScanner, VIVID910, and R700 with the gold standard 3-dimensional models of the SLP250. To assess the reliability of the 3-dimensional models, the shell/shell deviation of each model was calculated based on the same surface-based registrations for all 5 sets of dental casts. Results: OraScanner, VIVID910, and R700 were sufficiently accurate when compared with the gold standard. In the assessment of reliability, there were no significant differences between all comparisons. Conclusions: The results showed that the OraScanner system has a sophisticated algorithm for 3-dimensional surface registration and can be used to generate accurate and reliable 3-dimensional digital models for use by clinicians. (Am J Orthod Dentofacial Orthop 2013;144:619-25)

Over the past decade, the specialty of orthodontics has witnessed a marked proliferation in the use of 3-dimensional (3D) digital models for the purposes of storage, diagnosis, design of customized appliances, and orthodontic treatment outcome evaluations. Currently, a number of approaches can be applied to capture the digital representation of the 3D model. These might involve the use of structured or unstructured laser scanners to scan physical models in vitro. Also, various tabletop scanners have been designed to capture 3D images of either impressions or physical models to create 3D models. These scanners have an autorotating unit to minimize the blind area.

However, optical scanners with structured white light, such as the SureSmile OraScanner (Orametrix, Richardson, Tex), can be used both in vivo and in vitro to scan the dentition or a physical model, respectively, to create a 3D representation. More recently, products such as iTero (Align Technology, San Jose, Calif), CEREC (Sirona, Bensheim, Germany), and Lava COS (3M Unitek, St Paul, Minn) scanners have also been introduced in the marketplace with similar functionalities. Furthermore, industrial-grade CAT scanners have been applied to scan impressions. More recently, SureSmile has extended the use of cone-beam computed tomography to capture both in-vivo images of the dentition and in-vitro images of the physical models to create 3D digital representations of the dentition. Understanding the accuracy and reliability of these imaging devices is important because they might not only affect the measures of the rendered 3D image, but also influence the accuracy and precision of any customized appliance designed on the basis of the image. Currently, there is a lack of investigations to study the accuracy and reliability of many of these scanners.

The primary objective of this study was to assess the accuracy and the reliability of the OraScanner by...
comparing it with other desktop 3D scanners—VIVID910 (Konica Minolta, Tokyo, Japan) and R700 (3shape, Copenhagen, Denmark)—and a laser-based scanner, the SLP250 Laser Probe (Laser Design, Detroit, Mich), which served as the gold standard. The OraScanner was studied because it has the longest history of use in orthodontics to capture both in-vivo and in-vitro 3D images of the dentition and physical models, and yet little information is available on its performance characteristics.

MATERIAL AND METHODS

In this study, 5 sets of dental casts were used. First, all 5 sets were scanned with the OraScanner by an author (A.U.C.S.). The manufacturer of the scanner has reported that its accuracy is ±0.05 mm. The scanned data were sent automatically via the Internet with a firewall connection to the digital laboratory at OraMetrix. As part of the SureSmile service, the laboratory technicians created the digital models (shell model, gingiva model, model base, teeth model, and so on). Through the processes of denoising and refining the registration of the raw scanned data, the shell model was created; subsequently, the other models were created based on the shell model. However, only the shell models were used in this study.

Next, all 5 of the same models were scanned with the SLP250 Laser Probe. This scanning was outsourced. This was followed by desktop scanning of the same 5 models with the VIVID910 and the R700 by the same operator. The manufacturers reported that the accuracies of the SLP250, VIVID910, and R700 are ±0.01, ±0.10, and ±0.02 mm, respectively. The 3D models created by the SLP250 were used as the gold standard in this study because this scanning device has the highest accuracy compared with the others.

Cone-beam computed tomography (CBCT) was also used to assess the gold standard models as a part of this study. Ultrahigh-resolution industrial computed tomography is highly accurate. However, it is difficult to use 3D image sets with a standard personal computer because of the

Fig 1. Scanners used in this study: VIVID910, R700, and SLP250 Laser Probe. The OraScanner is attached to the Scanning Station (personal computer) with a fiber optic cable. The OraScanner consists of a handheld unit with a detectable mirror.
huge volumes of the data. So, the user-friendly CBCT data were used in this study. Trophy Pan Pro (Yoshida, Tokyo, Japan) was used; it has 0.09 mm of voxel resolution and 2.2 lp (line pairs) per millimeter of space resolution of the scan.

The 3D surface models of each dental cast were created from multiple scanned data to minimize blind sectors. Figure 1 shows the 3 scanners used in this study. The assessments of their accuracy were carried out by comparing each 3D model against the gold standard. The assessment of the reliability of the OraScanner was carried out by comparing it with each 3D model separately. This clarified the characteristics of the OraScanner by evaluating the stability of shape, distortion, and trend of magnification or reduction.

The accuracy of each scanner was studied by comparing the 3D models created by the OraScanner, VIVID910, and R700 with the gold standard 3D models created by the SLP250. The shell/shell deviation of each comparison was carried out by applying the least squares method to register each model (all 5 sets of models) using 3D reverse engineering software (Rapidform; Inus, Seoul, Korea). In this study, the maximum mean deviation set as a registration threshold was 0.01 mm that was expressed as

\[ \sum_{i=1}^{n} \left| X_i - X \right| / n = 0.01 \]

where \( X_i \) is each value in the data set, \( X \) is the mean of all values in the data set, and \( n \) is the number of values in the data set.

To assess the reliability of the 3D models created by the OraScanner, VIVID910, and R700, the shell/shell deviation of each model was calculated based on the same surface-based registrations for all 5 sets of dental casts (5 maxillary models, 5 mandibular models). The mean distance deviations of the 10 dental casts were calculated at each registration. Figure 2 shows the shell models created by the 3 systems.

**Statistical analysis**

Statistical analyses were carried out using “R” software (a language and environment for statistical computing, version 2.14.1; R Foundation for Statistical Computing, Vienna, Austria). Analysis of variance (ANOVA) was used to analyze the shell/shell deviation and
measure the differences between the various representations of the captured 3D shells of the models.

RESULTS

Figure 3 shows an example of registrations between 3D shapes created by OraScanner and SLP250 (top) and created by CBCT and SLP250 (bottom) as a gold standard.

Fig 3. An example of registration between 3D shapes created by OraScanner and SLP250 (top) and created by CBCT and SLP250 (bottom) as a gold standard.

Table I. Comparison of shell/shell deviation between the gold standard and each system (mm)

<table>
<thead>
<tr>
<th></th>
<th>SLP250-OraScanner</th>
<th>SLP250-VIVID910</th>
<th>SLP250-R700</th>
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<tr>
<td>Mean ± SD</td>
<td>0.058 ± 0.009</td>
<td>0.055 ± 0.008</td>
<td>0.050 ± 0.007</td>
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<tr>
<td>Significance</td>
<td></td>
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<td>NS</td>
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</table>

NS, Not significant.

Fig 4. A box plot of mean values of shell/shell deviations between OraScanner, VIVID910, and R700 and SLP250 as a gold standard.
and ±0.03 mm, respectively. Figure 4 shows a box plot of mean values of shell/shell deviations among OraScanner, VIVID910, and R700, with SLP250 as the gold standard. The maximum deviation was between SLP250 and OraScanner. However, the value was small (0.058 ± 0.009 mm). Table I shows the results of the 1-way ANOVA. There were no significant differences between all comparisons (P values less than 0.05 were considered significant). This demonstrated that OraScanner, VIVID910, and R700 are sufficiently accurate when compared with the gold standard.

Figure 5 shows the registered images between the 3 scanners for the reliability assessment. Each registration was carried out along with the model base because it is easy to understand how to superimpose. The regions of the model bases were not included for calculation of the shell/shell deviation. Figure 6 shows a box plot of mean values of shell/shell deviations of each comparison based on the systems. Table II also shows the results of the 1-way ANOVA. The mean values of the shell/shell deviations were small in each comparison. The difference in mean value of shell/shell deviations was only 0.012 mm, and there were no significant differences among all comparisons (P values less than 0.05 were considered significant).

**DISCUSSION**

In clinical orthodontic practice, dental cast analysis has an important role for not only diagnosis but also assessment of treatment outcome. To our knowledge, there are no universal standards for defining the accuracy of a model. However, in orthodontics, it is generally accepted that measurement accuracy up to 0.1 mm is adequate for clinical purposes and does not compromise the diagnostic value of a model. The use of 3D digital models captured by various devices for diagnosis, planning treatment, designing customized orthodontic appliances, and treatment outcome evaluations by the orthodontist is increasing. It is therefore important to establish...
the accuracy and reliability of the digitally rendered models and the performance guidelines.

In this investigation, the accuracy of the OraScanner, VIVID910, and R700 shell/shell deviations of the captured 3D images were compared with the gold standard images from the SLP250. The results of all comparisons showed that the mean values of the deviations were small (\(0.058 \text{ mm}\)). These results indicate that the OraScanner and the other scanners studied have sufficient accuracy and can be used by clinicians with confidence. Furthermore, the reliability of the 3D models created by the OraScanner, VIVID910, and R700 was also assessed by evaluating their respective shell/shell deviations. The results for all comparisons showed that the mean values of the deviations were small (\(<0.057 \text{ mm}\)). The results of this study indicate that OraScanner, VIVID910, and R700 are comparable in terms of both accuracy and reliability. Furthermore, it is also clear that the OraScanner, which was the only reference-free scanner studied, has a highly sophisticated algorithm for 3D surface registration. Reference-free scanning allows the operator to freely move the scanner to capture the image of an object as it moves. This is an important performance characteristic for in-vivo scanning. The VIVID910, R700, and SLP250 laser scanners used in this study are fixed-object scanners that cannot be used for in-vivo scanning. Future studies should assess the reliability and accuracy of the OraScanner against CBCT and some intraoral scanners such as the iTero.\(^{10,14}\)

**CONCLUSIONS**

To assess the accuracy and reliability of the OraScanner, the 3D dental models created by the SureSmile system were compared with the 3D models based on 3 other scanning systems: SLP250 Laser Probe, VIVID910, and R700. The shell/shell deviations for each comparison were small and appeared to be clinically insignificant. Furthermore, the results showed that the OraScanner system has a highly sophisticated algorithm for 3D surface registration and can be used to generate accurate and reliable 3D digital models for use by clinicians.

**REFERENCES**


![Fig 6. A box plot of mean values of shell/shell deviation on each comparison based on systems.](image-url)

<table>
<thead>
<tr>
<th>System Comparison</th>
<th>Mean ± SD</th>
<th>Mean ± SD</th>
<th>Mean ± SD</th>
<th>Significance</th>
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<tr>
<td>OraScanner-VIVID910</td>
<td>0.051 ± 0.007</td>
<td>0.057 ± 0.009</td>
<td>0.048 ± 0.006</td>
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<td>VIVID910-R700</td>
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NS, Not significant.
movement during orthodontic treatment. Angle Orthod 2009;79:
447-53.