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RESEARCH AND EDUCATION

Evaluation of the 3D error of 2 face-scanning systems: An in vitro analysis

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ABSTRACT

Statement of problem. Facial scanning systems have been developed as auxiliary tools for diagnosis and planning in dentistry. However, little is known about the trueness of these free software programs and apps for facial scanning.

Purpose. The purpose of this in vitro study was to evaluate the trueness of 3D facial scanning by using Bellus3D and +ID ReCap Photo.

Material and methods. A mannequin head was used as the master model. The control group was created by scanning the mannequin head with a noncontact structured blue light 3D scanner (ATOS Core). Two facial scanning methods were used for the experimental groups: a facial scanning app (FaceApp) and the Plus identity photogrammetry methodology (ReCap Photo). In both methods, image capturing was performed under the same natural lighting conditions with a smartphone (iPhone X) calibrated with an app. Trueness was assessed from the 3D measurement error, which was calculated with a 3D mesh analysis software program (GOM Inspect). Two comparison groups were created: ATOS versus Bellus3D (B3D) and ATOS versus +ID with ReCap Photo (+IDRP). The results were statistically evaluated by using the Shapiro-Wilk and paired t tests (α=.05).

Results. B3D had a greater error than +IDRP in measuring the regions of the upper and lower lips, nose, and mentum (P<.01). This error was statistically higher for +IDRP (P<.01) in the right face area, but the left face area showed no statistically significant difference between the evaluated scanning methods (P=.93). The 3D global trueness of B3D was 0.34 ±0.14 mm, and that of +IDRP was 0.28 ±0.06 mm.

Conclusions. Both methods evaluated in this study provided a 3D model of the face with clinically acceptable trueness and should be reliable tools for planning esthetic restorations. (J Prosthet Dent 2021;■:■-■)

Conventional methods for planning and evaluating esthetic dental treatments rely on 2-dimensional (2D) photographs, which limit the ability to evaluate and represent the patient's head and face. With the integration of different digital technologies such as intraoral and facial scanners, the concept of a 3-dimensional (3D) virtual patient has been developed and used for oral rehabilitation.[1-4]

Different 3D scanning techniques (Fig. 1), including 3D photogrammetry, have been developed. Some of these use high-cost systems, which restricts access for routine clinical procedures.[5-12] The generation of a 3D cast uses a specific software program which automatically records the common points of each image and then calculates the distance between them in 3D space. The result is a cloud of points that can be transformed into a 3D mesh.[13,14]

Photogrammetry can be divided into the stereophotogrammetry technique, in which all images are captured simultaneously by different cameras at different heights and angles relative to the object or patient, and

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Clinical Implications

This study compared the trueness of 2 affordable methodologies for facial scanning and contributes to the knowledge of imaging science in dentistry by allowing the clinician to plan an accurate guided treatment based on the patient's face.

the monoscopic photogrammetry technique, in which a single camera captures sequential images at different heights and angles relative to the object or patient.[13,15,16] The 3D photogrammetry technique is able to capture surface data in high-resolution color at relatively fast speeds, with the absence of radiation, straightforward training, and high 3D accuracy.[3,4,8,10,15,17,18]

Different innovative techniques for creating 3D face models have been recently published, including free user-friendly apps and software programs for mobile devices, tablets, and computers.[1,5,7,13,14,19-22] Salazar et al[13] reported a method of creating a standardized 3D facial model by using a mobile device and a, now discontinued, free software program (123D Catch; Autodesk Inc) through conventional photography. The same team recently published the "Plus Identity (+ID) Methodology," which enables the creation of high-resolution and accurate 3D facial models from smartphones and open-source software programs by using similar monoscopic photogrammetry principles.[14] Furthermore, novel apps for smartphones are available and have been reported to allow a 3D mesh capturing.[1,5,23] Some of these methods use the scanning principle of infrared light.[1,23] However, as few studies have evaluated 3D global accuracy of the whole face,[6,8,9,24] little is known about the trueness of these free software programs and apps for facial scanning. Thus, the purpose of this study was to compare the 3D error of 2 facial scanning methods: Bellus3D app versus +ID with the ReCap Photo (Autodesk Inc) software program. The null hypothesis was that the error of facial models would be similar for both methods.

MATERIAL AND METHODS

A mannequin was scanned with a noncontact structured blue light 3D scanner (ATOS Core; Zeiss CO) and used as the experimental system. The system comprised a coordinate measuring machine measuring millions of points per single scan or measurement. This scanner had 3 sensors in 1 system, allowing the production of high-quality data, even from shiny surfaces. Additionally, the scanner used the blue light technology to improve the scanning of dark-colored surfaces and objects with deep crevices or fine edges.[25] The scanner has been reported to have an accuracy of 3 μm and a repeatability of 2 μm for jaw scanning.[25]

The first experimental system was a facial scanning app (FaceApp; Bellus3D Inc). This technique has a noncontact optical instrument with a facial recognition camera system (iPhone X; Apple Inc). This camera system contains components that included infrared sensors, proximity sensor, ambient light sensor, flood illuminator, dot projector, and a 7-MP camera. To map facial anatomy, sensors and components work together to project 30 000 infrared dots on the user's face. The facial scanning app (FaceApp; Bellus3D Inc) can make a rapid high-resolution 3D data collection in a single procedure from the left ear to the right ear in approximately 15 seconds.[1,7] To verify the trueness of this system, the data collection from the mannequin was carried out according to the manufacturer's recommended protocol. The mannequin was positioned on a table with the Frankfurt plane parallel to the floor. During image captures, the same natural ambient lighting conditions and a white background were used. To ensure an effective data collection, an app for light calibration with 1600 lux of illuminance was used (Light Meter; WBPhoto). Ten 3D surface models were obtained and allocated to the first experimental group: Bellus3D (B3D). As this method allowed the export of the 3D model with actual measurements, calibration was not required.

The second experimental group was +ID workflow with ReCap Photo (+IDRP). To obtain the 3D model, photographs were made with a smartphone (iPhone X; Apple Inc) reverse camera, which consists of dual cameras, 12 MP (f/1.8, 28 mm) and 12 MP (f/2.4, 52 mm). The zoom or flash was not used. The 3D model was obtained from a sequence of 45 photographs by using the monoscopic photogrammetry +ID workflow and a software program (ReCap Photo; Autodesk Inc) to generate a 3D model. Photographic captures were made following the +ID protocol described by Salazar et al.[14] Once the 3D model was generated, it was calibrated by measuring the mannequin with digital calipers (Mitutoyo 150 mm; Mitutoyo). This procedure allowed the distance between the corner of the right eye and the left eye to be determined. All the captures were made under the same light conditions as for the first experimental group. Ten 3D surface standard tessellation language (STL) files (specimens) were obtained and allocated to the second experimental group (+IDRP).

After scanning, the 20 STL files were exported to a 3D mesh editing software program (ReCap Photo; Autodesk Inc). After this, the virtual models were cropped by using the "shortcut" tool, and the areas that were not to be assessed were removed to reduce the data size (Fig. 2). The next step was to export these STL files to a metrology software program (GOM Inspect; GOM a ZEISS Co) to perform the 3D analysis between the reference and test files. Comparisons were performed separately to analyze the 3D global deviation

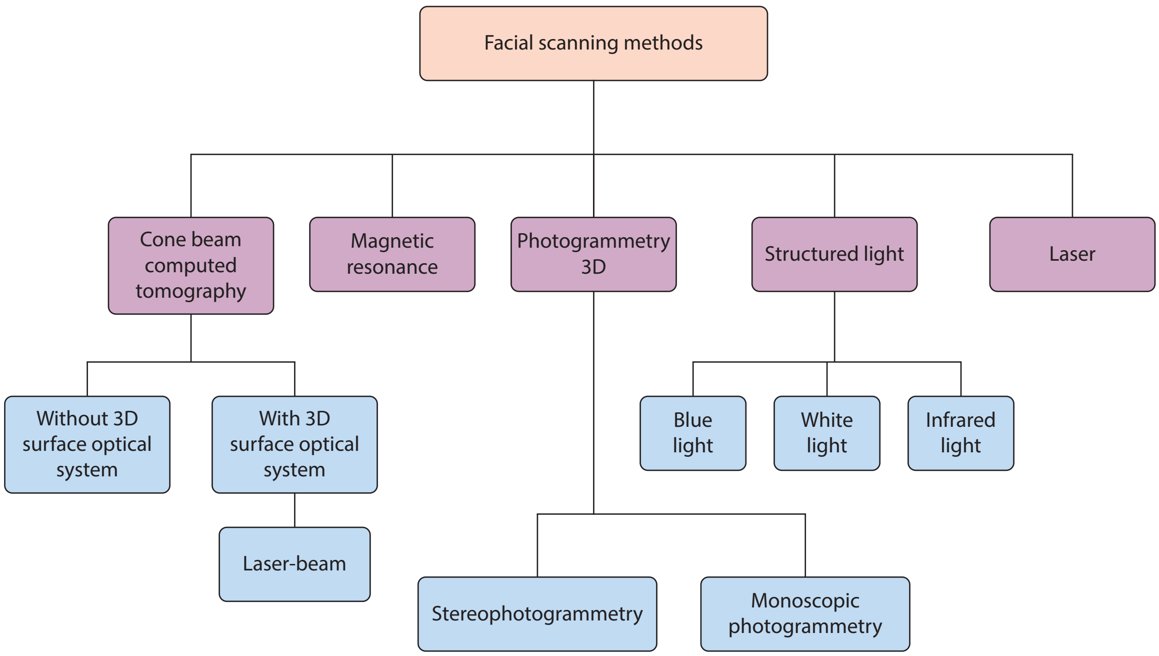

Figure 1. Facial scanning methods.

between the facial data sets: ATOS STL was compared with B3D STL and also with +IDRP STL. The software program aligned the scans with the master scan by using a best-fit algorithm. Once superimposed, a color map on which the closest distance between the data sets was set with a maximum acceptable deviation of 1 mm was created.[6,26] The predominance of green represented a perfect fit between the experimental and the reference system, whereas red and blue indicated positive and negative discrepancies in a range of 1 mm. The face was analyzed as a whole and then divided into 6 anatomic regions, upper lip, lower lip, mentum, nose, right face, and left face, which were analyzed individually.

Deviations between each experimental group and its respective reference model were then calculated by using a different measurement module in the "nearest" mode. This procedure calculated the mean absolute deviation between all the nearest signed neighbor points (trueness). Based on methods described by Bohner et al,[26] 30 to 50 points were included to create deviation in each of the 6 anatomic regions (Figs. 3,4). All landmarks were placed on the 3D images with the same coordinates for both groups: B3D versus ATOS and +IDRP versus ATOS. The average values were calculated to determine the total mean trueness for each region.[27] The 3D global accuracy was calculated as the average across all 6 regions for each scanning group.

Statistical analysis was performed by using a statistical software program (IBM SPSS Statistics, v26; IBM Corp). Normal distribution of data was confirmed by the Shapiro-Wilk test, and the mean deviation values given by B3D and +IDRP were compared by using a paired t test. Overall differences across all facial regions were assessed by two-way repeated ANOVA (α=.05). The Tukey test was used for post hoc adjusted comparisons.

RESULTS

A summary of descriptive statistics for scanning system trueness (for each location: upper lip, lower lip, mentum, nose, right face, and left face) is presented in Table 1. A statistically significant difference between the 2 methods was found for the upper lip, lower lip, mentum, nose, and right face (P<.05). No statistically significant difference was found between the 2 methods in the left face region (P=.93). When considering all facial regions together, B3D (0.55 ±0.37 mm) and +IDRP (0.55 ±0.84 mm) showed a similar measurement error. Individual variations between scanners for each facial region were not greater than 0.5 mm (Table 2). The highest mean difference was 0.41 mm in the left face area. The B3D group showed a higher 3D error than the +IDRP group in the upper lip, lower lip, nose, and mentum (P<.01). Regarding the right face region, the 3D error was statistically higher for the +IDRP group (P<.01) (Fig. 5).

A significant interaction was found between scanners and facial regions (Table 3). The post hoc test showed a statistically significant difference between frontal (upper

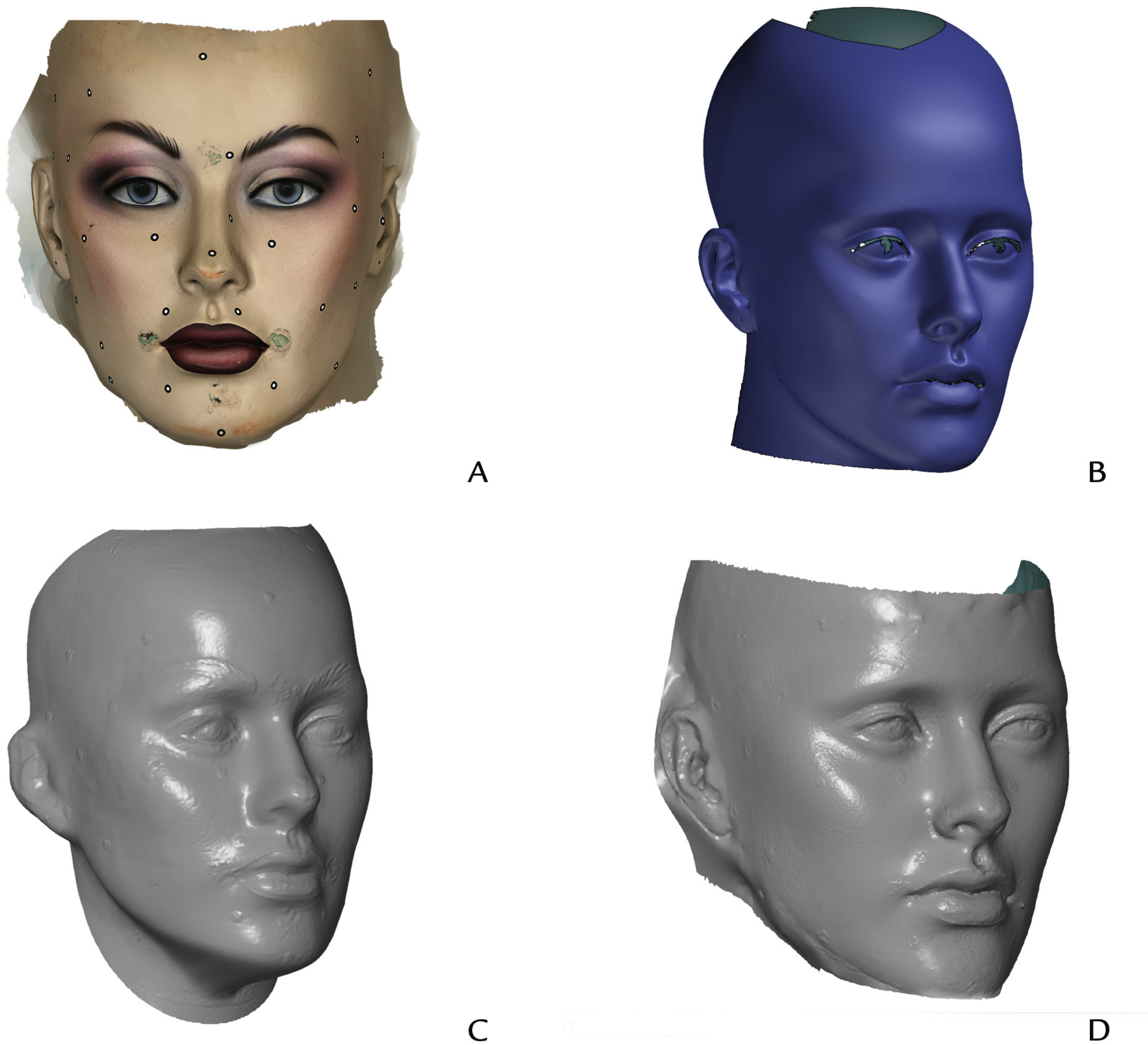

Figure 2. A, Frontal view of mannequin head. B, Virtual model (standard tessellation language file) obtained with noncontact structured blue light 3D scanner. C, Virtual model (standard tessellation language file) obtained with Bellus3D facial scanning app. D, Virtual model (standard tessellation language file) obtained with +ID ReCap plus identity photogrammetry methodology.

lip, lower lip, mentum, and nose) and lateral surfaces (left and right faces). Left and right faces did not differ between each other (P=.71).

Figure 6 displays the facial color maps of each group, representing the surface differences between Bellus3D versus ATOS and +ID ReCap Photo versus ATOS. This figure displays a scale of different colors, where green refers to minimum differences (approximately 0 mm), red to negative differences (>-1 mm), and blue to positive differences (>+1 mm). Gray refers to extrapolation of the scale, greater than a 1-mm difference. The evaluated facial scanning systems showed closer 3D global trueness. In B3D, the trueness was 0.34 ±0.14 mm, and 0.28 ±0.06 mm in +IDRP.

DISCUSSION

The purpose of this study was to compare the 3D measurement error of 2 facial scanning methods: B3D versus +IDRP. A mean overall surface difference was observed between 3D data tested in all the anatomic regions, except for the left face area. Thus, the null hypothesis was rejected.

The 3D measurement error of facial scanning systems has often been evaluated with traditional methods. These include anthropometric manual measurement techniques using measuring tapes or calipers.[3,4,7,10,12] However, these methods have limitations and require the operator to be carefully calibrated to avoid imprecise placement of

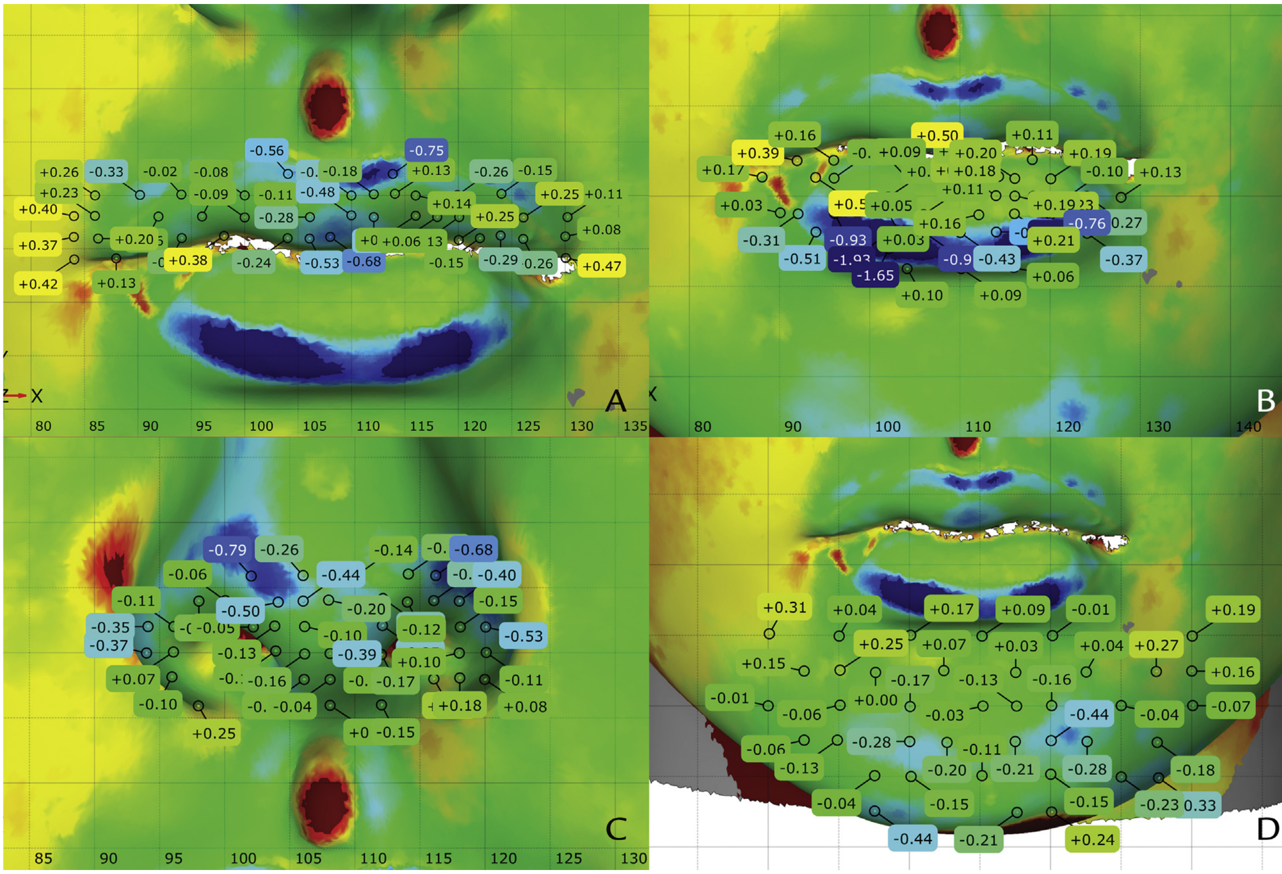

Figure 3. Frontal view of 3D analysis of selected points for each face group. A, Upper lip. B, Lower lip. C, Mentum. D, Nose.

landmarks.[18] In the present study, 3D deviation measurement was performed in an STL file by using a software program for 3D meshes analyses (GOM Inspect; Gom a ZEISS Co). This software program calculated the 3D error through a specific algorithm which relied exclusively on computer calculations, thus avoiding human measurement errors.[6,8,9,24] Moreover, this method allowed both the evaluation of the entire facial region and the evaluation of a specific area.[8]

Measurement error is defined as the difference between the true value and the measured value. It is composed of the systematic measurement error (SME), which is defined as closeness of agreement between a measured quantity value and a true quantity value of a measure, and the random measurement error (RME), which is defined as closeness of agreement between indications and measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.[8,27] In the present study, SME was defined as trueness and represented by the mean values, and RME was defined as the precision or repeatability and represented by the standard deviations. The present study demonstrated that images captured by the +ID workflow with ReCap Photo can be acquired with a high trueness value (0.28 mm) and high

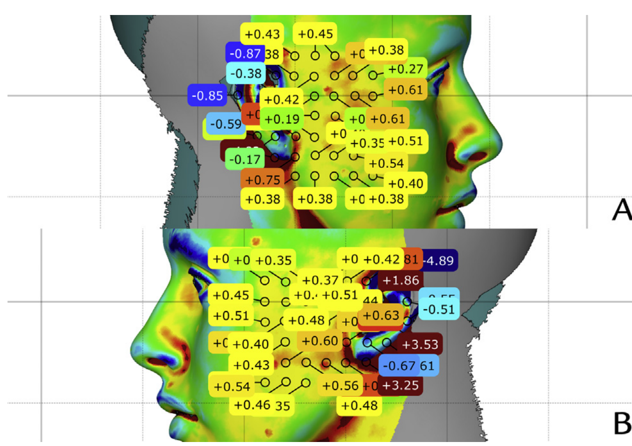

Figure 4. Lateral view of 3D analysis of selected points for each face group. A, Right face. B, Left face.

repeatability (±0.06 mm). Despite the similar value of trueness (0.34 mm), the Bellus3D system showed lower repeatability (±0.14 mm). Similar findings were reported by Piedra-Cascon et al[1] in a study using a dual-structured light scanner (Face Pro Camera; Bellus3D Inc). They reported a mean trueness value of 0.91 mm and a mean precision value of 0.32 mm. Additionally, Knoops et al[9] reported a deviation of 0.71 ±0.28 mm for a structured

Table 1. Descriptive statistics of Bellus3D and + ID ReCap systems

Face Area	Scanning System	Mean ±Standard Deviation (mm)	Confidence Interval (CI) 95% (Minimum Value; Maximum Value) (mm)
Upper lip	Bellus3D +ID ReCap	0.49 ±0.04 0.19 ±0.04	0.46; 0.52 0.15; 0.22
Lower lip	Bellus3D + ID ReCap	0.58 ±0.05 0.31 ±0.11	0.54; 0.62 0.23; 0.40
Nose	Bellus3D + ID ReCap	0.38 ±0.05 0.18 ±0.05	0.34; 0.41 0.14; 0.22
Mentum	Bellus3D + ID ReCap	0.36 ±0.03 0.20 ±0.11	0.33; 0.38 0.11; 0.28
Right face	Bellus3D +ID ReCap	0.53±0.13 1.09 ±0.52	0.43; 0.63 0.71; 1.46
Left face	Bellus3D + ID ReCap	0.79 ±0.15 0.66 ±0.21	0.67; 0.90 0.50; 0.81

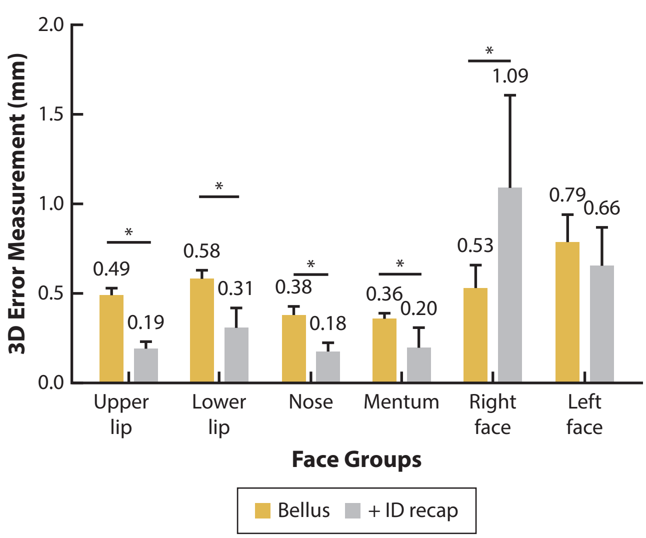

Figure 5. Box plot of 3D error measurement and *t* test analysis. *Statically significant difference (*P*<.05).

white light scanner (M4D; Rodin 4D SAS) and a deviation of 1.33 ±0.46 mm for a structured infrared light scanner (Structure Sensor; Occipital Inc).

The results showed a high 3D error in both systems when the lateral areas were evaluated (right and left face). These results should be interpreted cautiously because even though these systems are capable of 180-degree capture, the technique used in this study was not designed to capture the ear region. The excess coverage of the face angles in the lateral region is necessary to ensure the accuracy of the central region.[13,14] Moreover, if the objective had been to capture both ears, then additional captures may have been required by following a specific protocol for this area.[14,15] A similar effect was also observed by Koban et al,[5] with a greater deviation in the cheek region (0.68 mm) than in the central region (0.25 mm). The main advantages of the B3D method are its speed and agility. In the present research, this technique allowed the generation of a 3D

Table 2. Paired *t* test

Face Area	Mean Error (mm)	Confidence Interval 95% Minimum Value (mm)	Confidence Interval 95% Maximum Value (mm)	tvalue	*P*
Upper lip	0.30	0.24	0.35	12.03	<.001
Lower lip	0.26	0.18	0.35	7.15	<.001
Nose	0.20	0.15	0.24	11.02	<.001
Mentum	0.16	0.06	0.25	3.65	.005
Right face	0.55	-0.91	-0.20	-3.53	.006
Left face	0.01	-0.45	0.41	-0.08	.932

Table 3. Two-way repeated measurements ANOVA

Variable	Sum of Squares	Degree of Freedom	Mean Square	F	*P*
Scanners	0.21	1	0.21	6.77	.12
Scanners×facial region	2.57	5	0.51	16.62	<.001
Error	1.67	54	0.03	—	—

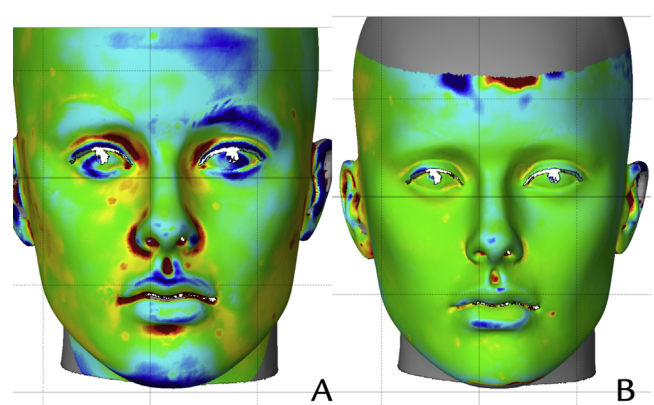

Figure 6. Difference color map of superimposition of ATOS control versus experimental groups. A, Bellus3D facial scanning app versus ATOS. B, +ID ReCap versus ATOS. ATOS, noncontact structured blue light 3D scanner; +ID ReCap, plus identity photogrammetry methodology.

image in 30 seconds. It also facilitated the export of the STL model, as compared with the +IDRP method. Thus, the B3D method showed greater effectiveness because of the automatic generation of the 3D model, which can be directly exported from the mobile device in many file formats in less than 1 minute. It also has other advantages: It is not invasive, it is reproducible, it has self-calibration, it is accurate, and it costs less.[1,7] However, limitations of this technique include sensitivity to light and the difficulty in scanning hair.[1,23]

In respect to the +IDRP method, the time for capturing and processing the images through the software program were quite long, depending on the hardware of the computer. However, this delay can be matched by the best performance of this method in the present study, consistent with studies evaluating sources of measurement error in other 3D systems.[6,8,9,24] The performance of facial scanners with a mean deviation of less than 2 mm has been reported to be sufficient for dental practice.[4,8,10] Both methods in the present study showed mean differences of less than 1 mm for all regions and are likely to be clinically acceptable, as deviations larger than 2 mm have been considered unreliable.[6]

In the present study, major deviations were observed in lateral areas. An accurate central facial area, including the mouth, seems to be achievable with these methods, which might also be acceptable tools for diagnosing or planning smile designs.

The precision and reproducibility of different face scanning systems have been evaluated.[2,6,11,12,22] Nonetheless, most of these image-capturing devices are expensive and may not be justified in clinical practice. Both scanning systems used in the present study are affordable and should help in the exchange of information and provide suitable tools for planning prosthodontics and esthetic dentistry.

Limitations of the present study included the use of a static model head; therefore, the results should be interpreted cautiously. Additional variables such as involuntary movements, hair, beards, deep facial grooves, and light sources that may affect the image quality and have been reported as artifacts of distortion[6,7,11] should be considered in future studies. Clinical studies are necessary to assess these related factors and their influence on the accuracy of 3D scanning systems.

CONCLUSIONS

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

1. The acquisition of 3D facial images with both methods used in this study demonstrated favorable trueness.
2. Straightforward use and low cost are probably the main benefits of both methods.

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