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RESEARCH AND EDUCATION

Accuracy (trueness and precision) of a dual-structured light facial scanner and interexaminer reliability

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ABSTRACT

Statement of problem. Digital waxing procedures should be guided by facial references to improve the esthetic outcome of a restoration. The development of facial scanners has allowed the digitalization of the extraoral soft tissues of the patient's face. However, the reliability of facial digitizers is questionable.

Purpose. The purpose of this study was to evaluate the accuracy (trueness and precision) of extraoral 3D facial reconstructions performed by using a dual-structured light facial scanner and to measure the interexaminer variability.

Material and methods. Ten participants were included. Six soft-tissue landmarks were determined on each participant, specifically reference (Ref), glabella (Gb), subnasal (Sn), menton (Me), chelion right (ChR), and chelion left (ChL). Interlandmark distances Ref-Sn, Sn-Gb, Ref-Gb, Sn-Me, and ChR-ChL (intercommissural) were measured by 2 different operators by using 2 different methods: directly on the participant' face (manual group) and digitally (digital group) on the 3D facial reconstruction of the participant (n=20). For the manual group, interlandmark measurements were made by using digital calipers. For the digital group, 10 three-dimensional facial reconstructions were acquired for each participant by using a dual-structured light facial scanner (Face Camera Pro Bellus; Bellus3D). Interlandmark measurements were made by using an open-source software program (Meshlab; Meshlab). Both operators were used to note 10 measurements for each manual and digital interlandmark distance per participant. The intraclass correlation coefficient between the 2 operators was calculated. The Shapiro-Wilk test revealed that the data were not normally distributed. The data were analyzed by using the Mann-Whitney U test.

Results. Significant differences were found between manual and digital interlandmark measurements in all participants. The mean value of the manual and digital group discrepancy was 0.91 ±0.32 mm. The dual-structured light facial scanner tested obtained a trueness mean value of 0.91 mm and a precision mean value of 0.32 mm. Trueness values were always higher than precision mean values, indicating that precision was relatively high. The intraclass correlation coefficient between the 2 operators was 0.99.

Conclusions. The facial digitizing procedure evaluated produced clinically acceptable outcomes for virtual treatment planning. The interexaminer reliability between the 2 operators was rated as excellent, suggesting that the type of facial landmark used in this study provides reproducible results among different examiners. (J Prosthet Dent 2020;124:567-74)

Successful oral rehabilitations involve comprehensive diagnosis and treatment planning.[1-4] The incorporation of facial references during digital waxing procedures provides esthetic references to ensure the integration of the prosthetic rehabilitation with the face.[1-6] Furthermore, visualization of the treatment outcome obtained through the simulation performed with a patient's face before treatment, enhances patient communication and increases the predictability of the result.[7-12]

The integration of facial references such as full-face 2D patient photographs at different positions or 3D extraoral soft-tissue reconstruction by using a facial scanner can be imported into a dental or open-source computer-aided design (CAD) software program to

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Clinical Implications

The facial scanner selected provided a reliable digitizing procedure of the extraoral soft tissues of a patient which could be considered when a virtual patient is created for treatment planning.

improve digital waxing.[13-15] A protocol of these digitizing procedures, creating the so-called virtual patient, has been described[13-21] and used to simulate the outcome of the proposed treatment plan into a 2D or 3D facial reconstruction of the patient.[13-15,17]

Different 3D facial scanning methodologies have been introduced, including photogrammetry (PG), stereophotogrammetry (SPG),[17,22-27] laser-beam scanning (LB),[28-30] and structured light scanning (SLS) (Table 1).[31-33] PG and SPG are passive methods of scanning the patient's face based on making 2 or more photographs from different perspectives with homologous common points to obtain the facial reconstruction through a reverse engineering software program. In contrast, LB and SLS use active 3D sensors for facial scanning procedures, where light patterns are projected onto the extraoral soft tissue of the patient's face to be captured by a high-resolution camera or cameras by using active triangulation.[31-35] Studies have reported the time of acquisition, calibration, initial investment, and maintenance for each facial scanner technology, identifying advantages and disadvantages (Table 1).[28,29,36]

A facial digitizer generates a specific digital file format such as standard tessellation language (STL), tessellation with polygonal faces (OBJ), or polygon or Stanford triangle (PLY) files. An STL file describes only the surface geometry of a digitized object without any representation of color, texture, or other CAD attributes.[37] In contrast, the OBJ and PLY files store information regarding surface color and texture.[37]

According to ISO 5725-1,[38] the term accuracy is a combination of trueness and precision. Trueness refers to the ability of the scanner to provide a 3D reconstruction as close to its true form as possible, and precision is the closeness of agreement between images acquired by repeated scanning procedures under the same conditions.

The purpose of this study was to measure the accuracy (trueness and precision) of a dual-structured light facial scanner and to measure the interexaminer reliability. The null hypotheses were that no significant differences in trueness and precision would be found between the soft-tissue interlandmark measurements performed manually and 3D facial reconstructions and that no significant differences in interexaminer reliability would be found among the interlandmark measurements performed by the 2 operators.

Table 1. Summary of advantages and disadvantages for each facial scanning technology

Technology	Advantages	Disadvantages
Laser beam	• Noninvasive • Accurate • Reproducible	• Long Scan times (8-30 s) • Various scans required • Sensitive to light and metal objects • Eye safety issues • Investment • Calibration
Stereophotogrammetry	• Noninvasive • Accurate • Reproducible • Only one scan required	• Daily specific calibration • Poor definition with shiny surfaces • Difficult to scan hair • Expensive • Dedicated room • Calibration
Photogrammetry	• Noninvasive • Accurate • Reproducible	• Various photographs required • Reverse engineering software needed • Sensitive to light • Calibration
Structured light	• Noninvasive • Accurate • Reproducible	• Various scans required • Sensitive to light and metal objects • Investment • Difficult to scan hair • Calibration
Dual-structured light with infrared sensors	• Noninvasive • Accurate • Reproducible • Only one scan required • Autocalibration	• Sensitive to light • Difficult to scan hair

MATERIAL AND METHODS

Ten completely dentate participants (8 women and 2 men) were recruited at a private dental practice in Madrid, Spain. All the participants agreed to volunteer to participate in the present project. All participants were informed about the purpose of the study and the associated procedures, and written consents were obtained. The inclusion criteria were the absence of craniofacial syndromes or deformities, facial scar tissue, and a history of facial trauma and maxillofacial surgery.

In order to facilitate posterior measurements, 6 anthropometric soft-tissue landmarks were identified and marked by using adhesive stickers (Adhesive stickers; Erich Krause GmbH) on each participant's face, including reference (Ref), glabella (Gb), subnasal (Sn), chelion right (CR), and chelion left (CL) (Fig. 1). The stickers had a 4-mm-diameter red dot and a 2-mm-wide white circle. The Ref point was selected and defined as an arbitrary point above Gb in the middle of the forehead because it is the zone that is least influenced by the lower third facial mimic and is located in the area of maximum resolution for the facial scanner used. New adhesive soft-tissue landmarks were placed on each patient and kept in position until all the measurements had been made.

Figure 1. Anthropometric landmarks determined by using adhesive stickers: reference (Ref), glabella (Gb), subnasal (Sn), chelion right (CR), chelion left (CL), and menton (Me). Interlandmark distances measured: Ref-Gb, Ref-Sn, Sn-Gb, Sn-Me, and intercommissural (ChR-ChL).

Linear measurements between the different landmark positions, namely Ref-Gb, Ref-Sn, Sn-Gb, Sn-Me, and intercommissural (CR-CL), were measured using 2 independent operators (W.P.-C., M.J.M.) who were blinded to each other's measurements by using 2 different methods: clinically on the participant's face (manual group) and digitally (digital group) on the 3D facial reconstruction of the participant.

For the manual group, interlandmark distances were measured for each participant by using digital calipers (FINO Digital Caliper; FINO GmbH) from the center of the red dot on an adhesive sticker to the center of another. The manufacturer of the digital calipers reports an accuracy of 0.01 mm. Participants were asked to sit upright adopting a natural head position, keep the eyes open looking toward the horizon, avoid facial expression, and maintain the maximum intercuspation position (MIP). Two measurements for each interlandmark distance were recorded.

For the digital group, 10 facial scans were consecutively carried out for each participant by using a dual-structured light scanner (Face Camera Pro Bellus; Bellus3D) connected to a tablet (Huawei MediaPad M3; Huawei) and controlled by a software program (Face Camera App; Bellus3D) (Table 2). The facial scanner incorporated 2 infrared laser structured light projectors and 3 camera sensors: 2 were infrared (1 megapixel; 1280×800 pixels) arranged in the lateral area of the device, and a 1-color sensor (2 megapixels; 1600×1200 pixels) was positioned centrally. The facial scan was calibrated before each acquisition procedure following the manufacturer's recommendations. Furthermore, clinical scanning conditions were standardized by seating the participants in an adjustable rotatable chair between 30 and 45 cm away from the

Table 2. Dual-structured light facial scanner (Face Camera Pro Bellus; Bellus3D) specifications provided by manufacturer

Output File Format	**.obj, .mtl, .jpeg, .stl, .yml**
Scanning modes	High-definition (HD), Standard-definition (SD)
Sensors	Two 1-megapixel infrared sensors (1280×800) One 2-megapixels color sensor (1600×1200)
Projectors	Dual-infrared structured light VCSEL projector
Field of view	Infrared sensors: 66 degrees (D) Color sensors: 69 degrees (D)
Optimal working range	30-45 cm
Optimal lightning	Indoors under room light
Operating systems	Android 7.0 with 4 GB RAM Windows 8 or 10 with 4 GB RAM
Scanning modes characteristics	SD mode: scan time, 25 s; processing time, 15 s HD mode: scan time, 25 s; processing time, 30 s

scanner and in a room with no windows and 10 000 lux (LX1330B Light Meter; Dr. Meter Digital Illuminance) and 4100 K illuminance. The scanning procedures were performed in high-definition (HD) mode. Participants were instructed to adopt the same facial expression and same position as described for the manual measurements. After each acquisition, the 3D facial reconstruction was opened and checked in the software apparatus to ensure the quality of the digitizing procedure by evaluating whether the adhesive soft-tissue landmarks had been scanned without distortion or duplication (Fig. 2).

The 3D facial reconstructions were based on a stereophotogrammetric algorithm and were exported in the OBJ file format. The same interlandmark distances measured in the manual group were measured on the 3D facial reconstructions by using a 3D mesh-processing open-source software program (MeshLab; MeshLab) with the measuring tool and by placing the cross-section arrow in the center of the red dot of one adhesive sticker to another (Fig. 3). Each interlandmark distance was measured 2 times.

The definition of trueness in the experiment was defined as the average absolute distance between the manual and the digital interlandmark distances, while precision was defined as the interlandmark distances between the manual and digital measurements. Furthermore, the interoperator reliability was calculated by using the intraclass correlation coefficient (ICC) between operators for each interlandmark distance. Manual measurements were established as the control group, and the absolute differences between the manual and digital measurements were analyzed.

Statistical analysis of data was performed by using a statistical software program (IBM SPSS Statistics, v24.0; IBM Corp). The Shapiro-Wilk test revealed that the data were not normally distributed. The data were therefore analyzed by using the Mann-Whitney U test (α=.05).

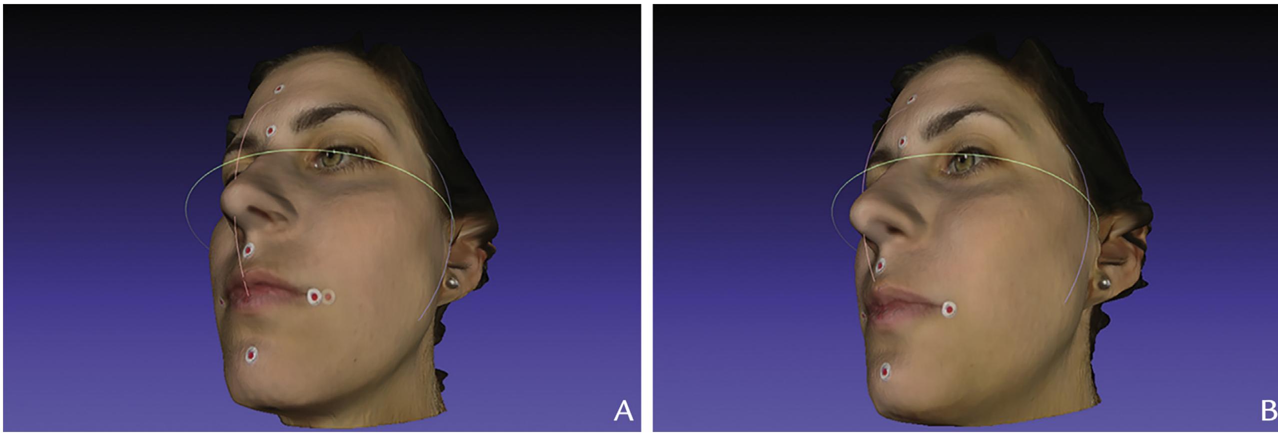

Figure 2. Three-dimensional facial reconstructions reviewed after each acquisition. A, Not validated 3D facial reconstruction from blurred and duplicated adhesive sticker. B, Validated facial scan with adhesive landmarks clearly scanned.

RESULTS

Significant differences were found between the manual and digital interlandmark measurements in all participants (Figs. 4, 5). The comparison between the manual and digital measurements revealed a mean absolute difference of 0.91 ±0.32 mm. The dual-structured light facial scanner tested obtained a trueness mean value of 0.91 mm and a precision mean value of 0.32 mm. Trueness and precision mean values for each interlandmark distance are presented in Table 3, and trueness and precision mean values for each interlandmark distance per participant are presented in Tables 4 and 5. Trueness values were always higher than precision mean values, indicating that the precision was relatively high.

The interexaminer reliability for each interlandmark measurement is presented in Table 6, with the lowest ICC at 0.93 for landmark Sn-Me. The mean ICC between the 2 operators was 0.99, which indicates the reliability of measurements made by different operators.

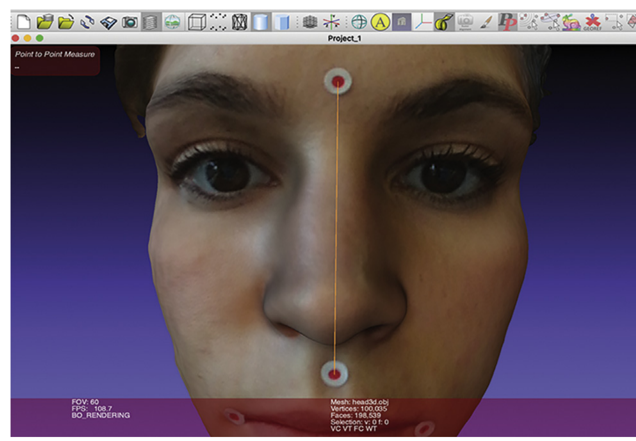

Figure 3. Digital measurements with measuring tool of 3D mesh-processing open-source software (MeshLab; MeshLab).

DISCUSSION

The purpose of this study was to measure the accuracy (trueness and precision) of the dual-structured light facial scanner selected and to measure the interexaminer reliability. Significant differences were found in the interlandmark distances between the manual and digital measurements, but excellent interexaminer reliability between both operators was obtained. Consequently, only the first null hypothesis was rejected.

Trueness in the experiment was defined as the average absolute distance between the manual and digital interlandmark distances, while precision was defined as the interlandmark distances between manual and digital measurements. Previous studies reported deviation values close to 1 mm,[22,26,27,31-33] but a discrepancy of up to 2 mm is considered clinically acceptable.[39] Kau et al[22] reported differences between physical models, and digital measurements obtained by using the SPG technology ranged from 0.22 ±0.1 mm to 1.20 ±0.46 mm. Ma et al,[31] Li et al,[32] and Ye et al[33] used structured-light scanning systems to obtain the facial reconstructions, reporting a mean discrepancy of 0.93 ±0.36 mm, 0.84 ±0.65 mm, and 0.58 ±0.37 mm, respectively, between the manual and digital measurements. Moreover, Liu et al[26] selected a PG system as a facial digitizer and reported a mean absolute difference of 1.95 ±0.33 mm between the analog and digital measurements. In the present clinical study, the trueness mean value and precision mean value obtained were 0.91 mm and 0.32 mm, respectively. The facial digitizer selected could be a reliable method of treatment planning for a digital waxing procedure.

Digitalization with the facial scanner required 15 seconds to acquire the data; therefore, the participant had to remain still during the capturing time. Small movements would cause inaccuracies on the facial reconstruction and may have impacted the results of the

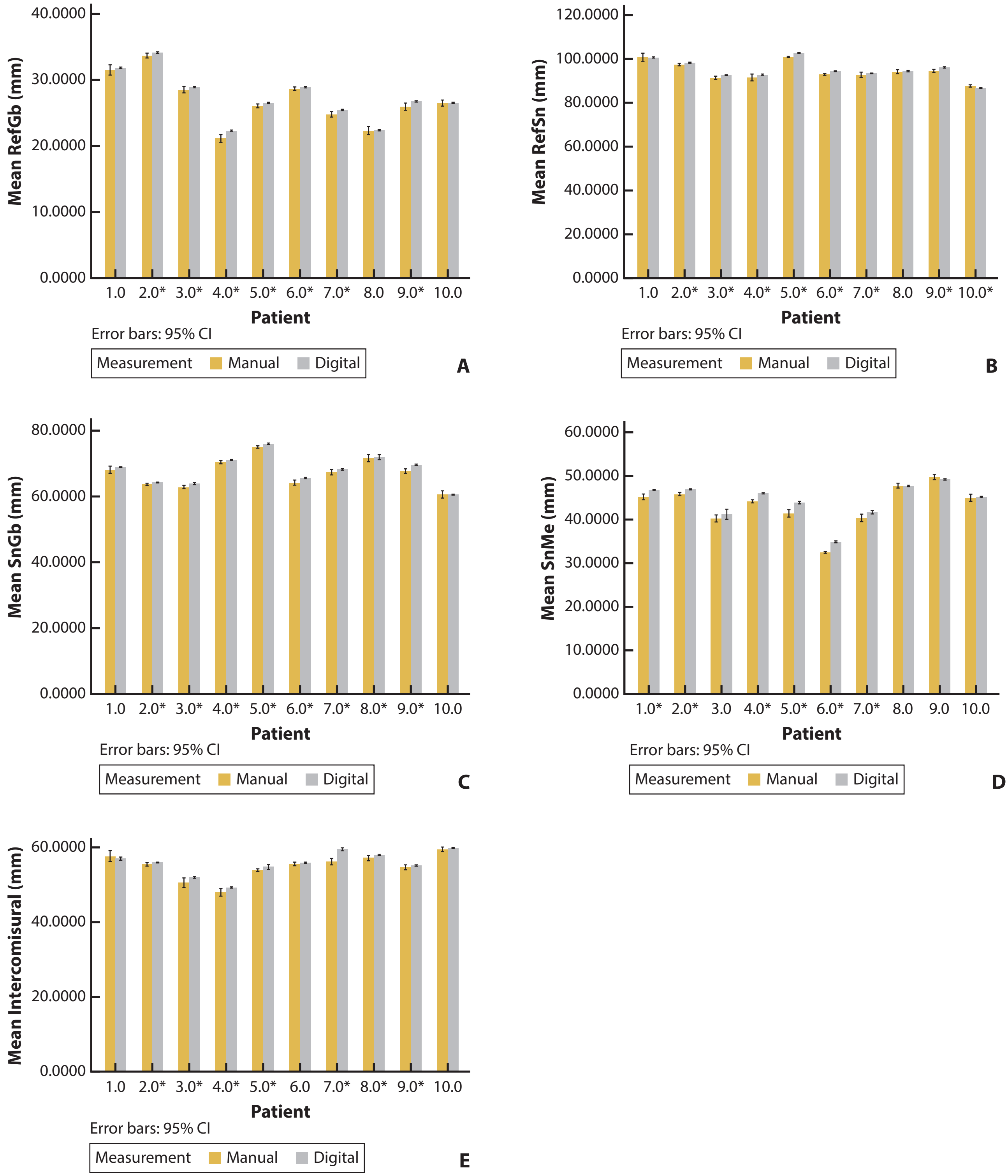

Figure 4. Mean values for interlandmark manual and digital measurements obtained. Significant differences ($P<.05$) marked with asterisk. A, Ref-Gb. B, Ref-Sn. C, Sn-Gb. D, Sn-Me. E, Intercommissural (CR-CL).

present study. However, specific instructions were transmitted to the participants to minimize this error.

Previous authors have discussed the convenience of using anatomic structures as landmarks or the placement adhesive landmarks to perform linear measurements. However, when using anatomic structures as landmarks, determination of the same position between different examiners may be difficult.[25-32] In the present study,

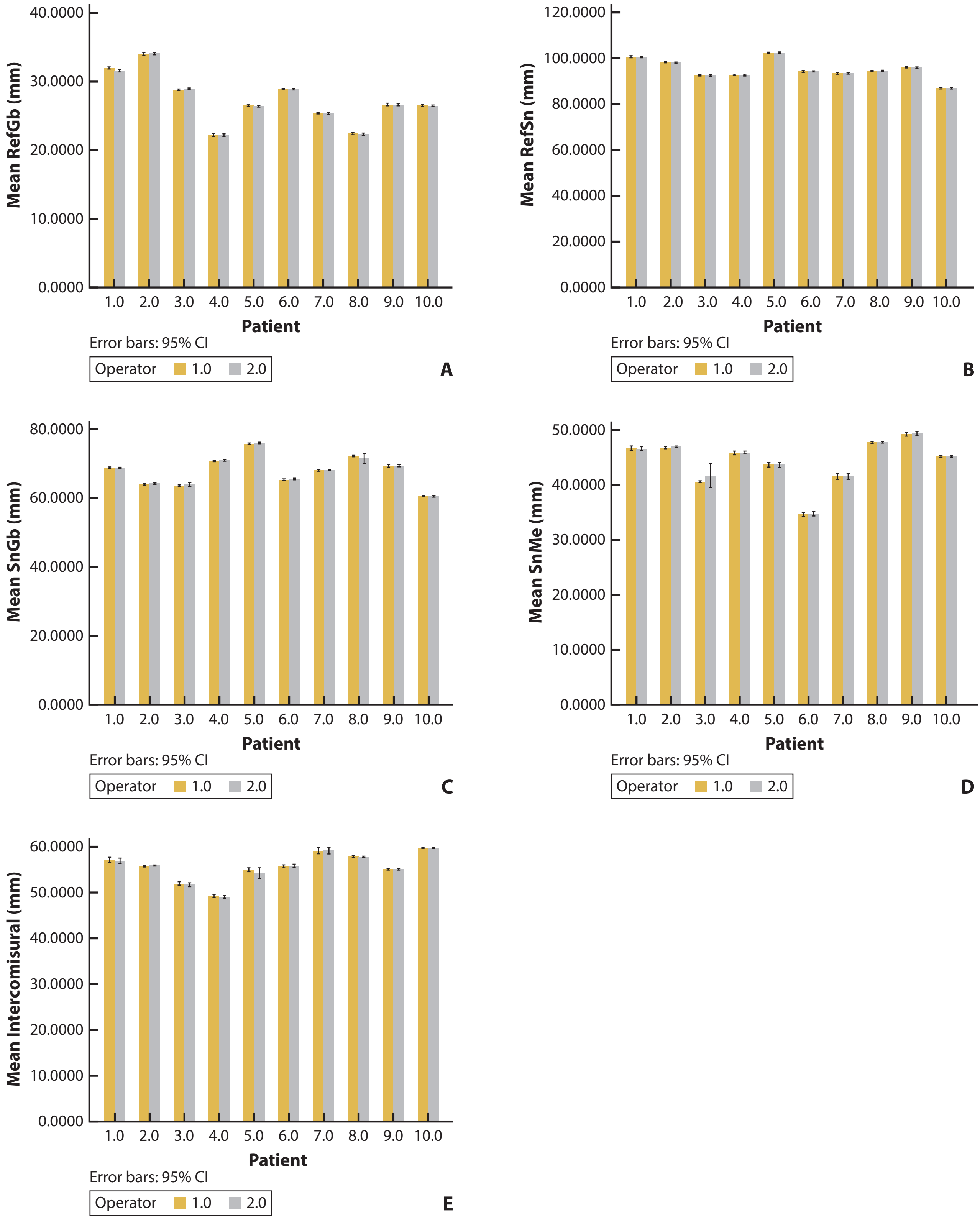

Figure 5. Mean values for interlandmark measurements obtained from 2 operators. A, Ref-Gb. B, Ref-Sn. C, Sn-Gb. D, Sn-Me. E, Intercommissural (CR-CL).

adhesive stickers were used as landmarks to perform different measurements. The digital interexaminer reliability between the 2 examiners was excellent (0.99), which indicates that this type of facial landmark provides reproducible determination among different operators. It suggests that this type of landmark could be a reliable

Table 3. Trueness and precision mean values obtained for different interlandmark distances analyzed

Interlandmark Distance	Trueness (mm)	Precision (mm)
Ref-Gb	0.45	0.07
Ref-Sn	1.01	0.25
Sn-Gb	0.85	0.4
Sn-Me	1.25	0.52
Intercommissural	0.99	0.37

Table 5. Precision mean values obtained for Ref-Gb, Ref-Sn, Sn-Gb, Sn-Me, and intercommissural interlandmark measurement for each participant

Participant	Ref-Gb	Ref-Sn	Sn-Gb	Sn-Me	Intercommissural
1	0.08	0.74	0.38	0.26	0.43
2	0.2	0.04	0.14	0.06	0.01
3	0.14	0.05	0.38	3.12	0.05
4	0.07	0.43	0.21	0.17	0.12
5	0.07	0.28	0.34	0.21	1.8
6	0.01	0.07	0.17	0.21	0.38
7	0	0.2	0.03	0.61	0.74
8	0.02	0.19	1.79	0.07	0.06
9	0.07	0.23	0.09	0.36	0.06
10	0.07	0.29	0.45	0.15	0.01

Table 4. Trueness mean values obtained for Ref-Gb, Ref-Sn, Sn-Gb, Sn-Me, and intercommissural interlandmark measurement for each participant

Participant	Ref-Gb	Ref-Sn	Sn-Gb	Sn-Me	Intercommissural
1	0.3	0.2	0.87	1.58	0.63
2	0.39	0.87	0.52	1.13	0.43
3	0.42	1.24	1.1	0.97	1.48
4	1.17	1.3	0.51	1.85	1.36
5	0.45	1.54	1.03	2.46	0.79
6	0.24	1.45	1.4	2.48	0.24
7	0.66	0.75	0.84	1.28	3.29
8	0.08	0.28	0.26	0.04	0.82
9	0.79	1.56	1.91	0.53	0.44
10	0.02	0.84	0.02	0.15	0.38

Table 6. The interoperator reliability calculated with intraclass correlation coefficient (ICC) between operators for each interlandmark distance evaluated

Interlandmark	ICC Between 2 Operators
Ref-Gb	0.99
Ref-Sn	0.99
Sn-Gb	0.97
Sn-Me	0.93
Intercommissural	0.97

marker when superimposition procedures between 2 meshes are required.

The facial scanner used in this study had advantages over other noncontact facial scanning technologies as shown in Table 1. The system can produce a complete 3D facial reconstruction in a single procedure from the left ear to right ear, without the need of additional scans, and the scanning time is relatively short (approximately 15 seconds). Also, this facial scanner device uses infrared sensors that ensure speed and eye safety during the scanning procedures.

In the present study, the facial measurements made in the digital group were made on an OBJ file by using an open-source software program. While the STL file format contains information of the surface geometry of a digitized object without color information, the OBJ file stores information regarding surface color and texture. Further studies are needed to compare measurements performed on STL files. Furthermore, only 1 facial landmark was analyzed, and different scanning conditions may result in different accuracies on the 3D facial reconstructions.

CONCLUSIONS

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

1. The dual-structured light facial scanner tested obtained a trueness mean value of 0.91 mm and a precision mean value of 0.32 mm. Trueness values were always higher than precision mean values, indicating that precision was relatively high.
2. The mean value discrepancy between the manual and digital interlandmark measurements was 0.91 ±0.32 mm, which was clinically acceptable for the digitizing procedure for virtual treatment planning purposes.
3. The interexaminer reliability between the 2 operators was rated as excellent (0.99), suggesting that the type of facial landmark used in this study provides reproducible measurement among different examiners.

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