Facial scanner accuracy with different superimposition methods – In vivo study

Original article

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ABSTRACT

Purpose: To compare trueness and precision between conventional and digital facial measurements and to evaluate the accuracy of different superimposition techniques for facial scans. Materials and Methods: Twenty volunteers were recruited. Predetermined facial landmarks were marked with a black pen, and the interlandmark distances were measured manually with a conventional caliper and digitally with Geomagic software. Two consecutive facial scans were performed and superimposed using as best-fit reference the full face, the face without the eyes, and the bone-supported areas (eg, forehead and zygomatic areas) in order to assess root mean square (RMS) differences. Trueness and precision were evaluated and compared between the conventional and digital techniques. Mann-Whitney U and Kruskal-Wallis post hoc tests were used. The significance level was established at \( \alpha \) = .05. Results: Trueness between conventional and digital measurements was 1,151.75 ± 1,265.52 \( \mu m \) (3.04% ± 4.82%), and precision was 322.31 ± 300.54 \( \mu m \) (0.93% ± 1.10%). Global mean RMS values for each superimposition technique were 334.15 ± 172.07 for the full face, 339.57 ± 173.13 for the face without the eyes, and 385.65 ± 182.29 for the bone-supported areas, with the latter presenting statistically significant differences compared to the other two. Conclusion: Although statistically significant differences were detected in facial measurements, they were below the clinically detectable threshold. Superimposition with the full face and the face without
the eyes area presented smaller discrepancies than with the bone-supported areas, with higher discrepancies in the lower third of the face. *Int J Prosthodont* 2021. doi: 10.11607/ijp.7253

**INTRODUCTION**

Digital technologies have made way into dental medicine, promoting the shift from conventional techniques to virtual-based methodologies in the clinical practice and dental laboratory. Nowadays, one of the main focuses of digital dentistry is to increase the predictability and efficiency of dental treatments by developing technologies and techniques that allow creating a three-dimensional (3D) virtual patient in which the treatment plan could be virtually simulated.\(^1,2\)

The superimposition of files obtained with an intraoral scanner (IOS), cone-beam computer tomography (CBCT), and a facial scanner is still not well-known. However, its application in a 3D virtual patient could allow simulating oral rehabilitation treatments, assessing and quantifying clinical outcomes, which could be used to improve communication with the patient and colleagues, and also obtaining high-precision anatomical documentation.\(^3-11\)

The analysis of facial landmarks in dentistry is still mostly performed by analog methods using manual measurement devices, where the distance between anthropomorphic points is determined using a caliper directly on the face.\(^12,13\) Despite being a simple, non-invasive, low-cost method, it does not take into consideration the 3D complexity of the human face. Additionally, the pressure against soft tissues can decrease the accuracy and reliability of this technique.\(^3,12,14,15\)

More recently, the use of full-face imaging with 3D extraoral soft-tissue reconstruction through facial scanning was described as a method to determine changes in volume
and facial projection;\textsuperscript{5,11-13,15-18} this methodology is closer to the “virtual patient” concept.\textsuperscript{1,2,19} Facial morphology is captured by collecting a reflection of the face,\textsuperscript{4,11,12} which provides its 3D topography – thereby contrasting with the more limited information provided by conventional 2D photography.\textsuperscript{3,6,7,11,12,14}

Facial scanning has been suggested as a time-saving tool in clinical evaluations, as it allows data storage and retrievability, contributing to patients’ documentation and interdisciplinary treatment planning.\textsuperscript{4} Additionally, due to being a non-contact and non-invasive method, it reduces the patient’s discomfort. Facial scanning creates 3D facial models in a Wavefront object (.obj) or Polygon File Format (.ply) file formats, which capture real skin texture and color,\textsuperscript{11,14,20} thus allowing for better landmark determination than standard tessellation language (.stl) files, which only convey surface geometry.\textsuperscript{21}

Most of the commercially available facial scanners are expensive and can be complex to use in the clinical setting.\textsuperscript{3,22} However, thanks to technological developments, newer scanners are smaller, user friendly, and their manufacturers also report them as capable of reliable measurements; thus, they may be a viable and cost-effective option.\textsuperscript{8,10,23}

A high level of accuracy in 3D imaging is clinically crucial to ascertain treatment outcomes.\textsuperscript{7,8,24} However, there is a lack of scientific evidence related to the trueness and precision of such devices. Piedra-Cascón et al.\textsuperscript{21} compared facial measurements between conventional and digital methods and obtained mean trueness and precision values of 0.91 millimeters (mm) and 0.32 mm, respectively, with the digital method providing similar or better values. However, when comparing facial scans obtained at different time points to analyze treatments in the orofacial region (e.g., orthognathic surgery, orthodontics, or oral rehabilitation with dental prostheses), the
facial superimposition methodology still needs to be further developed to allow accurate comparative measurements. To the authors’ knowledge, a facial scan superimposition methodology that provides accuracy in the evaluation of changes in orofacial morphology is yet to be described. Therefore, this study aimed to compare trueness and precision between conventional and digital facial measurements and to evaluate different superimposition methodologies in facial scans obtained at different times from the same patient. The null hypotheses were that no statistically significant differences would be found in trueness and precision between conventional and digital linear facial measurements and that no statistically significant differences would be found between the three superimposition methods proposed.

MATERIALS AND METHODS

This in vivo study was conducted in compliance with the World Medical Association Declaration of Helsinki, approved by the local ethics committee, and registered at the U.S. National Library of Medicine ClinicalTrials.gov website under the reference number NCT04050878. Twenty volunteers from a private clinical setting were recruited according to the following inclusion criteria: be over 18 years old and considered as exclusion criteria the presence of facial hair, beard, mustache, or any other craniofacial deformity that would interfere with facial landmark determination. They were instructed not to use makeup, earrings, glasses, facial products, or any other addons during the facial scan procedures. Each volunteer was thoroughly informed about the purpose of the study and signed an informed consent agreement before entering the study.
- **Patient preparation**

Firstly, facial points previously described by Anas et al.\textsuperscript{12} and Jayaratne et al.\textsuperscript{25} were marked in each volunteer’s face with a black Sharpie pen (permanent ink type, model number B146, fine point, round toe, China), in the following positions: trichion (T), glabella (G), right exocanthion (RE), left exocanthion (LE), pronasal (Pn), subnasal (Sn), upper lip (UL), right cheilion (RC), left cheilion (LC), lower lip (LL), and pogonion (Pg) (Fig. 1). Then, measurements were made considering the outer segment of each determined mark in order to improve measurement reproducibility.

- **Facial scanner characteristics and scanning procedure**

The tested device is considered a low-cost facial scanner, easily accessible for use in the clinical setting (Bellus3D, Inc. Los Gatos, CA, USA). It contains two infrared laser structured-light projectors and three camera sensors – one color sensor and two infrared sensors, to which a smartphone with an external color camera is connected to capture the face. It has a working range of 25 to 60 cm that is established and controlled by the Bellus3D proprietary software.\textsuperscript{7,20,21}

The scanner was connected to a smartphone (Xiaomi Mi A2 Lite, Android version 9, Xiaomi, China) via USB, and the manufacturer’s instructions were followed. A standardized set-up was created in a room with controlled illumination (4100 K) and an adjustable mobile phone tripod. Scanner calibration was performed between each volunteer in order to improve scanning conditions as much as possible. All images were captured in the high-definition mode.

Each participant sat in a swivel chair and was asked to keep a natural head position and a resting posture, with relaxed lips. The height and closeness of the scanner were defined according to an internal parameter of the software. The volunteers were
asked to turn their heads in different directions, following the software instructions. Each subject face was scanned twice with a ten-minute interval.

- **Conventional measurements**
Two operators (R.A. and R.P.) performed conventional linear measurements with a digital caliper (PEREL, 150mm/6”, 0.01 mm accuracy) between the predetermined locations: T-G, G-Sn, Pn-Pg, UL-stomion(St), St-LL, RE-LE, RC-LC, RE-RC, and LE-LC. The operators were blinded to each other’s measurements. Volunteers were instructed to keep a natural head position and avoid facial expressions in order to prevent bias in the measurements.

- **Digital measurements**
The .obj files of each volunteer’s 3D reconstructed faces were imported to the reverse engineering software Geomagic Control X (3DSystems, USA) by two operators (R.A. and R.P.), and calibrated by previously established methods for digital analysis. In summary, virtual points were created in the outer part of the black dots marked with the Sharpie pen to digitally measure the inter-landmark distances for comparison with the corresponding gold-standard manual measurements. Each operator measured each distance five times.

- **Superimposition methods**
Facial alterations caused by expressions, emotions, or treatments performed in the orofacial area can interfere with scan superimposition in the reverse engineering software. Thus, three different methods were proposed and tested for accuracy: full
face (FF), face without the eyes area (WE), and bone-supported areas only (BS) (e.g., forehead and zygomatic areas) (Fig. 2).

Two operators (R.A. and R.P.) aligned the facial scans by previously described methods. The operators were blinded to each other’s measurements. Areas of 15 mm² or at least 60 polyfaces were created and centered with the same dots, to compare the two scans of each patient. The “3D Compare” function provided the root mean square (RMS) quantitative values of each location to measure differences between the two scans in each superimposition method, with three replicates performed per location and the mean considered for statistical analysis. For 3D visualization, qualitative colored maps of the discrepancies were obtained, where the comparison model (second scan) moved outwards from the reference (first scan) in red and inwards in blue. The tolerance level was defined at 100 microns (µm) and indicated in green (Fig. 3).

- **Statistical analysis**

The outcomes were defined as the trueness and precision of conventional (gold standard) and digital distances in predetermined facial landmarks, and the accuracy of three different superimposition methods between two consecutive facial scans.

In this study, trueness and precision were defined by previously established methods, briefly: trueness was defined mean absolute differences between manual and the digital interlandmark distances, while precision as interlandmark distances between the conventional and digital measurements. Finally, for the superimposition methods analysis, RMS values obtained with Geomagic for each location in the different superimposition methods by repeated scanning procedures under the same conditions was compared.
The intraclass correlation coefficient (ICC) was determined to assess inter-operator agreement in the analog and digital methods, based on the two-way random model, a consistency analysis, and 95% confidence intervals. ICCs were interpreted according to Fleiss, as follows: ICC < 0.40 = poor reliability; ICC > 0.40 but ICC < 0.75 = fair to good reliability; and ICC > 0.75 = excellent reliability.

Normality of distribution was tested by the Shapiro-Wilk normality test, and the Levene test was used to assess the equality of variance. According to the results, the non-parametric Mann-Whitney U and Kruskal-Wallis tests were used to compare RMS between methods in different locations (α=0.05). When performing multiple comparisons, the p-value was adjusted according to the Bonferroni correction method. The data obtained were presented as mean and standard deviation (SD) of the RMS in µm for the different superimposition methods. All calculations were carried out with the SPSS statistical software (version 25.0, SPSS Inc., Chicago, Illinois, USA).

RESULTS

The sample’s gender distribution was one male to nineteen females, its mean age was 31.9 years old (range: 24–48), and it was comprised of one Black and nineteen Caucasian individuals.

The ICC score between operators was 0.989 [0.987; 0.991] for the conventional measurements and, regarding superimposition methods, 0.997 [0.996; 0.998] for AF, 0.996 [0.995; 0.997] for WE and 0.981 [0.974; 0.986] for BS. All values were above 0.75, corresponding to excellent reliability between operators.

The precision observed in conventional and digital measurements of inter-landmark distances ranged between 229.20 ± 122.69 µm and 396.89 ± 386.18 µm, in UL-St
and RE-RC measurements, respectively, corresponding to dimensional changes of 2.76 ± 1.51% to 0.55 ± 0.52%. Trueness values ranged between 644.42 ± 526.47 µm (5.66 ± 4.68%) and 1949.90 ± 1529.16 µm (2.68 ± 2.00%) in the St-LL and RE-RC distances, respectively. The values for each inter-landmark measurement are depicted in Table 1. The statistically significant differences in trueness values between facial measurements are represented in Table 2.

Regarding the superimposition methods, mean and SD values were 334.15 ± 172.07 µm for FF, 339.57 ± 173.13 µm for WE and 385.65 ± 182.29 µm for BS. All values are presented in Table 3, and the significant differences between superimposition methods in each location in Table 4.

**DISCUSSION**

Based on the results, the digital method was reliable, repeatable, and comparable to the gold-standard analog measurements; thus, the first null hypothesis was not rejected. On the other hand, the proposed superimposition methods presented good results, with higher variability in the lower third of the face where statistically significant differences were found; thus, the second null hypothesis was rejected.

The interexaminer reliability was considered excellent, with overall mean trueness and precision of inter-landmark distances of 1151.75 µm and 322.31 µm, respectively, corresponding to a discrepancy of 3.04% and 0.93% between conventional and digital measurements. A study with a similar methodology reported discrepancies of 910 µm for trueness and similar precision between conventional and digital measurements.²¹ Liu et al.,³¹ who evaluated facial scans of edentulous patients and compared clinical and digital measurements, obtained a mean absolute difference of 1.95 ± 0.33 mm (1950 ± 330 µm). These results may derive from using
a facial camera system based on a stereophotogrammetric algorithm with multiple
digital single-lens reflex cameras to construct the 3D dataset, instead of a facial
digitizing system created for that purpose, such as Bellus3D.

When evaluating the different inter-landmark distances, we observed the highest
discrepancies between the far distant inter-landmarks right and left exocanthion-
canthion, as shown in Table 3. This finding is consistent with other studies that have
reported worst results in cheek, oral and orbital regions,\(^5,6,9\) and could also be
influenced by the distance between inter-landmark points. Nevertheless, all detected
discrepancies were below the described clinically acceptable threshold of 2 mm.\(^21,31\)

To the authors’ knowledge, this was the first study to test different superimposition
methods for their accuracy with facial scans. All the proposed methods were reliable
for facial scan superimposition. However, the BS method presented statistically
significantly higher discrepancies when compared to the FF and the WE methods,
even though it was still below the previously referred clinical threshold.\(^21,31\) The
obtained results could be related to the use of a smaller mesh area, which decreases
the superimposition algorithm’s capability to match the two scans, thus presenting
higher RMS discrepancy values.\(^5,21\)

The highest RMS discrepancies in the superimposition methods were identified in the
lower third of the face (right and left canthions) and the lowest discrepancies in the
upper third (trichion and glabella). Based on the results obtained, the authors suggest
that the lower third of the face should not be considered when using the
superimposition methodology for evaluating orthodontic, prosthodontic, or surgical
treatment changes regarding lip support, the vertical dimension of occlusion, or
anteroposterior changes. This approach would allow the superimposition of multiple
scans over the treatment period in order to quantify with higher reliability the obtained
outcomes, thus increasing treatment predictability. The proposed technology and superimposition methods still present limitations, mainly dependent on the presence of facial skin artifacts or skin color that can influence facial landmark determination or facial scanner capture, although, to the best of our knowledge, this is the first time that volumetric methodology is used for the evaluation of facial changes with accuracy and repeatability. Presently, extraoral photos and analog measurements provide a low level of precision because there are no permanent reference points to guarantee the repeatability of the measures. Therefore, the proposed methodologies present clinical value as they overcome this problem with high reproducibility.

From a cost-benefit perspective, the facial scanner used in this study presented promising values in a range of clinical measurements with acceptable accuracy, and the proposed superimposition methodologies could be used for comparing facial modifications in different time points or to evaluate vertical dimension or prosthetic lip support during oral rehabilitation. However, in order to achieve an accurate “virtual patient,” more clinical studies are needed to ascertain measurement stability over time and assess whether its use is practical in the clinical setting.

**CONCLUSION**

The present study suggests that facial scanning can be used for measurements between facial landmarks with high reproducibility, and is comparable with the gold-standard technique. Moreover, the proposed superimposition methodologies proved to be adequate for the evaluation of orofacial modifications between facial scans at different times throughout the treatment.
ACKNOWLEDGMENTS

The authors report no conflicts of interest.

REFERENCES


FIGURE LEGENDS

**Figure 1** – A - Facial landmarks represented by black circles: T, G, RE, LE, Pn, Sn, UL, RC, LC, LL, and Pg, and a caliper measuring the RE-RC distance; B - Facial scan where the same inter-landmark distance is measured digitally.

**Figure 2** – Mesh superimposition methods evaluated: considering the (a) full face (FF), (b) the face without the eyes area (WE), and (c) only the more bone-supported areas (BS) (e.g., the forehead and zygomatic areas).

**Figure 3** – Color-coded map representing RMS discrepancies between the two consecutive scans. Max/min nominal ± 100 μm (green). Max/min critical ± 1000 μm (dark red and dark blue).
Fig 1a

Fig 1b
Fig 3
TABLES

Table 1 – Mean (± SD) trueness and precision values for inter-landmark distances (µm) between conventional and digital methods.

<table>
<thead>
<tr>
<th>Inter-landmark Distances</th>
<th>Trueness</th>
<th>Trueness (%)</th>
<th>Precision</th>
<th>Precision (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-G</td>
<td>1032.91 ± 2079.79</td>
<td>1.87 ± 3.24</td>
<td>344.17 ± 357.14</td>
<td>0.65 ± 0.61</td>
</tr>
<tr>
<td>G-Sn</td>
<td>1018.55 ± 841.58</td>
<td>1.59 ± 1.24</td>
<td>336.20 ± 360.27</td>
<td>0.52 ± 0.52</td>
</tr>
<tr>
<td>Pn-Pg</td>
<td>1376.63 ± 958.25</td>
<td>1.98 ± 1.60</td>
<td>373.76 ± 45.98</td>
<td>0.51 ± 0.61</td>
</tr>
<tr>
<td>UL-St</td>
<td>716.09 ± 816.26</td>
<td>8.86 ± 10.64</td>
<td>229.20 ± 122.69</td>
<td>2.76 ± 1.51</td>
</tr>
<tr>
<td>St-LL</td>
<td>644.42 ± 526.47</td>
<td>5.66 ± 4.68</td>
<td>236.32 ± 147.60</td>
<td>2.02 ± 1.18</td>
</tr>
<tr>
<td>RE-LE</td>
<td>1396.54 ± 1120.202</td>
<td>1.36 ± 1.11</td>
<td>369.82 ± 289.17</td>
<td>0.36 ± 0.29</td>
</tr>
<tr>
<td>RC-LC</td>
<td>926.15 ± 1052.02</td>
<td>1.56 ± 1.73</td>
<td>289.16 ± 180.03</td>
<td>0.49 ± 0.31</td>
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<tr>
<td>RE-RC</td>
<td>1949.90 ± 1529.16</td>
<td>2.68 ± 2.00</td>
<td>396.89 ± 386.18</td>
<td>0.55 ± 0.52</td>
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<tr>
<td>LE-LC</td>
<td>1304.54 ± 1346.43</td>
<td>1.80 ± 1.75</td>
<td>325.28 ± 178.03</td>
<td>0.46 ± 0.25</td>
</tr>
<tr>
<td>Global</td>
<td>1151.75 ± 1265.52</td>
<td>3.04 ± 4.82</td>
<td>322.31 ± 300.54</td>
<td>0.93 ± 1.10</td>
</tr>
</tbody>
</table>

SD – standard deviation; µm – microns; T-G – trichion-glabella; G-Sn – glabella-subnasal; Pn-Pg – pronasal-pogonion; UL-St – upper lip-stomion; St-LL – stomion-lower lip; RE-LE – right exocanthion-left exocanthion; RC-LC – right canthion-left canthion; RE-RC – right exocanthion-right canthion; LE-LC – left exocanthion-left canthion
Table 2 – Statistically significant differences in trueness values between the facial measurements.

<table>
<thead>
<tr>
<th></th>
<th>T-G</th>
<th>G-Sn</th>
<th>Pn-Pg</th>
<th>UL-St</th>
<th>St-LL</th>
<th>RE-LE</th>
<th>RC-LC</th>
<th>RE-RC</th>
<th>LE-LC</th>
<th>Global</th>
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<td>St-LL</td>
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<td>RE-LE</td>
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<td>RC-LC</td>
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<td>RE-RC</td>
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</table>

T-G – trichion-glabella; G-Sn – glabella-subnasal; Pn-Pg – pronasal-pogonion; UL-St – upper lip-stomion; St-LL – stomion-lower lip; RE-LE – right exocanthion-left exocanthion; RC-LC – right canthion-left canthion; RE-RC – right exocanthion-right canthion; LE-LC – left exocanthion-left canthion
Table 3 - Mean (± SD) RMS of the predetermined locations using the three superimposition methods (µm).

<table>
<thead>
<tr>
<th>Location</th>
<th>FF Mean (RMS)</th>
<th>WE Mean (RMS)</th>
<th>BS Mean (RMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichion</td>
<td>170.95 ± 96.51</td>
<td>153.51 ± 82.15</td>
<td>131.41 ± 56.80</td>
</tr>
<tr>
<td>Glabela</td>
<td>160.97 ± 80.67</td>
<td>199.18 ± 87.49</td>
<td>175.60 ± 90.40</td>
</tr>
<tr>
<td>Right Exocanthion</td>
<td>246.32 ± 151.56</td>
<td>270.77 ± 190.27</td>
<td>255.04 ± 149.07</td>
</tr>
<tr>
<td>Left Exoconthion</td>
<td>234.11 ± 113.83</td>
<td>260.92 ± 134.21</td>
<td>260.13 ± 153.09</td>
</tr>
<tr>
<td>Pronasal</td>
<td>241.05 ± 150.96</td>
<td>246.43 ± 151.20</td>
<td>289.71 ± 205.57</td>
</tr>
<tr>
<td>Subnasal</td>
<td>367.68 ± 252.23</td>
<td>349.83 ± 237.80</td>
<td>470.57 ± 272.14</td>
</tr>
<tr>
<td>Upper Lip</td>
<td>470.90 ± 397.13</td>
<td>462.81 ± 392.27</td>
<td>667.60 ± 509.91</td>
</tr>
<tr>
<td>Right Canthion</td>
<td>688.94 ± 598.60</td>
<td>679.12 ± 587.87</td>
<td>876.86 ± 712.20</td>
</tr>
<tr>
<td>Left Canthion</td>
<td>670.94 ± 517.78</td>
<td>651.07 ± 496.03</td>
<td>819.39 ± 652.64</td>
</tr>
<tr>
<td>Lower Lip</td>
<td>359.32 ± 230.62</td>
<td>343.54 ± 213.88</td>
<td>564.81* ± 361.36</td>
</tr>
<tr>
<td>Pogonion</td>
<td>236.32 ± 126.28</td>
<td>227.89 ± 119.37</td>
<td>480.78* ± 344.32</td>
</tr>
<tr>
<td>Global</td>
<td>334.15 ± 172.07</td>
<td>339.57 ± 173.13</td>
<td>385.65* ± 182.29</td>
</tr>
</tbody>
</table>

FF - full face; WE - face without the eyes area; BS – bone-supported areas; RMS – root mean square;

* - Statistically significant differences between superimposition methods
**Table 4 – Statistically significant differences between locations for each superimposition method.**

![Comparison of locations with statistically significant differences](image)

- **T** – trichion; **G** – glabella; **RE** - right exocanthion; **LE** - left exocanthion; **Pn** – pronasal; **Sn** – subnasal; **UL** - upper lip; **RC** - right cheilion; **LC** - left cheilion; **LL** - lower lip; **P** - pogonion

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