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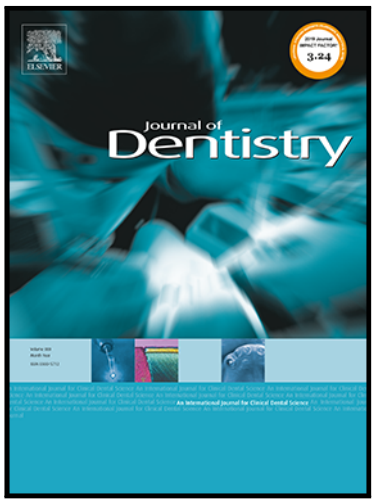


# Reliability of a face scanner in measuring the vertical dimension of occlusion

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# Reliability of a face scanner in measuring the vertical dimension of occlusion

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**Abstract**

**Objective:** This study evaluated the reliability of a face scanner in measuring the vertical dimension of occlusion (VDO).

**Methods:** Fully dentate volunteers (n=20; mean-age=30.0±10.7 years) were recruited. Clinical facial measurements were obtained using a digital caliper and a face scanner (Class 1 LASER, Obiscanner, Fifthingenium, Italy). The scans were imported into a mesh-processing software, and the distances were measured digitally. Measurements were obtained for each participant with the jaws positioned in maximal intercuspation (MI) and with increased vertical distances of 2, 4, and 6 mm. Vertical and horizontal measures were obtained using facial anatomical landmarks: Glabella (GL), Pronasale (PrN), Subnasale (SbN), inferior border of the right and left Alare, Labiale superius (Ls), right and left Cheilion (Ch), Soft Pogonion (SPg), right and left Tragus of the ear (Tr), for all selected vertical positions. Data analysis included intra-class correlation coefficient (ICC), pairwise comparison tests, Bland-Altman plots, and Passing-Bablok regression.

**Results:** 120 VDO measurements (clinical=60, digital=60) were recorded by two independent evaluators. Mean differences between digital and clinical measurements ranged from 0.054±0.14mm to 0.203±0.13mm. All parameters were strongly correlated ($r>0.93$; $p<0.001$). ICC estimates revealed excellent reliability, and the measuring procedure yields the same results on repeated trials irrespective of the raters and measurement methods. Bland-Altman plots revealed a difference between digital and clinical measurements of 1.7% for the vertical measurements. Regression analysis revealed no significant proportional difference between the two methods, so both can be used interchangeably.

**Conclusions:** The findings of this study demonstrate that VDO can be measured accurately from face scans using 3D mesh-processing software and

that even small changes in the VDO could be detected using the digital methods.

**Clinical Significance:** Findings provide evidence about the reliability of a digital method for jaw relation registrations and may be applied towards incorporating this method into clinical workflows for CAD-CAM dentures.

**Keywords:** Vertical dimension of occlusion, Jaw relations, 3D Face scan, Digital complete dentures, Removable prosthodontics, Geriatric Dentistry.

## 1. Introduction

Face scanners have exponentially increased in dentistry, and studies have demonstrated the many benefits of incorporating a face scanner into the clinical workflows [1-6]. The face scanners, combined with other devices and acquisitions, can virtualize a 3D replica of the patient, which serves as an important tool for diagnosis and treatment planning, monitoring outcomes or treatment predictability, as well as in education and inter-professional communication [7-14]. The accuracy and reliability of 3D images from different face scanners have been extensively evaluated, and the deviations in measurements were found to fall within the clinically acceptable ranges and may be considered reliable. [15-19].

The incorporation of digital technology in oral rehabilitation protocols has resulted in the modification of the conventional clinical workflows, an improved trueness in the fabrication methods, the utilization of processing materials with better mechanical properties, a diminution of overall treatment time as well as the laboratory processing time, the diminution of costs, and in providing better treatment outcomes with an increased patient satisfaction [20].

Oral rehabilitations with a fully digital workflow should consider reliable methods for jaw relation procedures. This study attempted to digitize one aspect of jaw relation registration procedures, the recording of vertical dimension of occlusion (VDO). The study aimed to test the reliability of measuring the different heights of vertical dimension of occlusion on 3D images acquired by face scanners and then compare them with the measurements made clinically, in healthy dentate volunteers. Based on the aims of this study, the primary null

hypothesis set for the study was that there are no differences between the distance measurements made digitally on 3D facial images and the analog clinical measurements made directly on the face. The secondary hypothesis set for this study was that it is not possible to measure or identify small changes in the vertical dimension of occlusion on the 3D facial images.

## 2. Materials and methods

### 2.1 Ethics statement

A request for the clarification of responsibility was sent to the relevant ethics committee (XXX) and the committee decisioned that this study did not require a formal ethics approval (XXXXX Nr. Req-2023-00163). A written informed consent was obtained from all volunteers before the start of the study.

### 2.2 Sample size

The required sample size for the current study using an effect size |ρ|= 0.6546387 and with α err prob = 0.05 and a power of (1-β err prob) of 0.95 was calculated to be 17 participants, which was in accordance with previously published similar reports [10, 17]. The calculated actual power for the sample size of 17 was found to be 96.6% (δ = 3.571; Critical t = 1.753; Df = 15). Assuming a dropout rate of 15%, the final total sample size was fixed at 20 volunteers. In case of non-significant correlations, a post hoc sample size calculation was planned. The sample size calculation was performed using a validated free software (G*Power, version 3.1.9.6 for Mac OS X 10.7 to 14, Düsseldorf, Germany) [21].

### 2.3 Participants

Healthy fully-dentate volunteers were requested to participate in this study. Participants with no gender restrictions were recruited if they were adults, aged 18 years and over, with intact or minimally restored dentition, had no facial asymmetries or scars, did not have pain during the time of recruitment or procedure, and upon receiving an informed consent. Participation was completely voluntary, and the participants could withdraw from the study at any point in time. Volunteers with signs and symptoms of temporomandibular

disorders, or with a history of functional or neurological diseases were excluded from the study sample.

2.4 Anatomical landmarks and face scanning

Eleven commonly used soft tissue landmarks were identified and marked on the face with a conventional marker (Staedtler permanent, Germany) and included, Glabella (G), Pronasale (PrN), Subnasale (SbN), Soft Pogonion (SPg), midpoint of the left Tragus of the ear (TrL), midpoint of right Tragus of the ear (TrR), inferior border of the left Alare (AL), inferior border of the right Alare (AR), left Cheilion (ChL), right Cheilion (ChR), and Labiale superius (Ls), as seen in the Figures 1 and 2 [22-25].

After the landmarks were identified and marked by the examiner, the face was scanned using a class 1 laser scanner with two light emitting diodes (with varying intensity levels), equipped with ports for connecting external lights, as well as an infrared structured red-light laser projector, along with a pair of sensors that comprised of a color sensor and an infrared sensor (Obiscanner, fifthingenium, Milan, Italy). This was a fast new generation face scanner specifically designed for digital dentistry to acquire a 3D model of the patient's face. It is composed by a RGB Camera 1080p at 30 frames, with an Infrared (IR) Laser Projector System, up to 200FPS Infrared, class 1 Laser Compliant, obtaining a face model with 40K/60K polygons, scanner range 30-90 cm (optimal position 50 cm). The average time for completing the scan (acquisition + elaboration) was approximately 15 seconds.

The face scanning was done under standardized conditions, and the procedure was maintained constant for all participants. The resultant scan image was exported in .stl, .obj, and in .ply, file formats to ensure that all the marked landmarks were visible on the open source system mesh processing and editing 3D triangular meshes (Meshlab_64bit_fp, Version 2022.02, https://www.meshlab.net/#) [26].

2.5 Distance measurements

In this study, two categories of distances were measured: vertical distances (VDO) and horizontal distances from the side of the face. The VDO was measured in three distances between the following landmarks:

1. GL and SPg
2. PrN and SPg
3. SbN and SPg

Furthermore, to detect small changes in the VDO, three custom-made rectangular resin blocks of 2mm, 4mm, and 6mm thickness were printed and placed between the jaws in the region of the central incisors to create a simulated increase in the VDO and was measured. Hence the four VDO recordings were done for each participant between each of the of the above-mentioned landmarks: one at maximum intercuspation and three measurements with the blocks in place at 2mm, 4mm and 6mm separation. In addition, three horizontal distances were measured for both sides of the face between:

1. TrL and AL, TrR and AR
2. TrL and ChL, TrR and ChR
3. TrL and Ls, TrR and Ls

All the measurements were first made directly on the face using a digital Vernier caliper (Walter Digital Caliper, Walter Werkzeuge GmbH, Salzburg, Austria). Then the measurements were made digitally on the face scans that had been imported in to the mesh processing software. All measurements were done by two independent evaluators. Digital measurements on the scan were made using the software's built in measuring tool. Each measurement by each evaluator, for both clinical and digital, was repeated three times and the evaluators were blinded to each other's measurements.

## 2.5 Data analysis

Statistical analyses included descriptive statistics and pairwise group comparison for paired measurements, under the assumption of normality of data distribution. Pearson's correlation coefficient was used to measure the linear correlation between the sets of data. The intra-class correlation coefficient (ICC) was used to measure the reliability index in the intra- and inter- rater reliability analyses, to assess the degree of correlation and the agreement between measurements obtained using clinical procedures and scanned 3-D facial images. A two-way mixed-effects model was used to assess the reliability of the two raters in the reliability experiment (inter-rater reliability), as well as for the intra-rater reliability with the two measurement methods (clinical and digital

measurements). The selection of ICC definition was based on the absolute agreement between raters (or if different raters assign the same score to the same subject), considering that the agreement between two raters is of interest (or the extent to which y equals x), including systematic errors of both raters and random residual errors. Based on the 95% CI of the ICC estimates, values <0.5, between 0.5-0.75, between 0.75-0.9, and >0.90 were indicative of poor, moderate, good, and excellent reliability, respectively [27].

Bland-Altman plot was constructed by plotting the difference between the measurements of the two compared methods against the mean of the two measurements. The mean difference was considered to reflect the systematic bias, and if the 95% CI of the bias contained the value 0, no significant systematic bias between methods was assumed. Provided that differences between measurements are normally distributed, 95% of the data points should lie within 1.96 SD of the mean difference (95% limits of agreement. The bias was assumed as clinically relevant if the 95% limits of agreement ranged outside the limits for the allowable total errors.

Then, the non-parametric Passing-Bablok regression, calculated the regression line equation from the two data sets, was used to test if the measures obtained by the two methods were comparable within the investigated concentration range. The regression procedure fitted the parameters *a* and *b* of the linear equation y = a + b x using non-parametric methods. If 0 was in the CI of *a*, and 1 was in the CI of *b*, the two methods could be considered as identical; or if these assumptions were not valid, there was a systematic difference ($a \neq 0$) and a proportional difference between the two methods ($b \neq 1$). The Passing-Bablok procedure would only be used on variables that had a linear relationship and were highly correlated. Statistical analyses were performed using the MedCalc Statistical Software version 20.218 (Ostend, Belgium; https://www.medcalc.org; 2023). The level of significance for statistical inferences was set at 5%.

## 3. Results

Twenty healthy fully-dentate volunteers (n = 20: women: n=10, men: n=10) with a mean age of 30.0 ± 10.7 years old participated in this study.

The difference between the paired measurements obtained with the face scanner and the clinical measurements (reference), according to the facial parameter and the interocclusal distance is shown in Table 1. Mean differences ranged from 0.054 (±0.14) to 0.203 (±0.13) and were significantly greater with the face scanner for most of the parameters. All parameters were strongly correlated ($r>0.93$; $p<0.001$).

ICC estimates revealed excellent reliability for almost all intra-rater correlations (ICC<0.90) or, when considering the lower limits of their 95% CI, at least good reliability (ICC between 0.75-0.9) as shown in Table 2. Similarly, excellent inter-rater reliability was observed for the clinical measurements (ICC<0.94), and perfect reliability when using the scanner (ICC ranging from 0.999 – 1.000). In summary, ICC measurements showed that, within the experiment, the measuring procedure yielded the same results on repeated trials irrespective of the raters and measurement methods.

The assessment of measurement error is shown in the Bland-Altman plots in Figure 3 and 4. Considering all the data, the mean percent difference between the scanner and clinical measurements was 1.7% (95%CI = -1.51 – 1.89%), with the 95% limits of agreement between -2.4 and 5.8%. Lower % differences were observed for the Glabella – soft Pogonion measurements (mean=1.1; 95%CI=0.87 – 1.30%). Mean % difference for the horizontal measurements were 2.9%.

Considering the high linear correlation between measurements with the two methods, the Passing-Bablok regression was performed, and the results are presented in Table 3. For the VDO measurements, a regression equation was obtained ($y = 0{,}027 + 1{,}01\ x$), the 95% CI for intercept included value zero and it could be concluded that there was no significant constant difference between the two methods. Respectively, the 95% CI for slope included value one, and it can be concluded that there was no significant proportional difference between the two methods. Therefore, it can be assumed that $x = y$ and that there was no significant difference between the methods, so both can be used interchangeably. The correlation between the predicted values by the regression model and the observed values ($y = 0{,}073 + 0.99\ x$; $r = 1{,}00$; $p < 0{,}001$) is shown in Figure 5. Due to the large sample size ($n = 480$ measurements) and the narrow 95% CI's for the intercept and slope, the results

are less likely to be biased. Regarding horizontal measurements, the regression equation (y = 0.484 + 0.98 x) revealed a systematic and proportional error, suggesting that the interchangeable use of the methods would lead to biased results (Figure 6).

## 4. Discussion

Digital dentistry has become an essential component of modern dental practice, and there is a growing tendency to using digital technologies to improve diagnosis, treatment, and overall patient care [12,20]. Within this context, the incorporation of a face scanner could be envisaged as a reliable and accessible way to preserve visual information through life, as a digital file, and used for rehabilitation purposes and as a medico-legal document if prosthetic, orthodontic or other type of treatment was intended. This is a non-contact optical measuring instrument that can acquire 3D facial models in open data format with real skin texture color, and a scanning process that was typically very fast [28]. The use of a CAD software could facilitate the communication with patients and among the interdisciplinary dental team, aiming to improve the predictability of dental interventions, especially complex prosthodontic rehabilitations.

Conventional methods of facial analysis include two-dimensional (2D) photographic, vernier caliper and bevel protractor measurements, aiming to measure the 2D projection of facial distances as well as angles [28]. However, the rapid advancement and evolution in optical scanning and designing technologies has led to a shift from 2D to three-dimensional (3D) workflows, leading to transferring of extraoral and intraoral clinical information into a virtual environment [29]. Nevertheless, the reliability and accuracy of face scanners in oral and maxillofacial prosthodontics was a major focus of current research.

In our study, no differences were found between manual and digital measurements, and a high inter- and intra-operator measurement consistency was encountered for the VDO measurements obtained digitally and byusing conventional methods (caliper), between the selected reference marks located on the glabella, tip of the nose, and pogonion. Zhao et al. [28] found that the 3D accuracy of different facial partitions was inconsistent when assessing facial deformities, although all tested scanners met the requirements for clinic use

[28]. Inaccuracies may also be related to small movements of the head during the capture [30]. Piedra-Cascón et al. [30] observed that the facial digitizing procedure produced clinically acceptable outcomes for virtual treatment planning, with the interrater reliability between two operators rated as excellent, suggesting that the type of facial landmark used in this study provides reproducible determination among different examiners [30]. Nevertheless, similar to our study, significant differences were found between the manual and digital measurements in all participants, with a mean absolute difference of 0.91±0.32 mm, which may be considered as clinically acceptable for virtual treatment planning purposes [30]. Other studies reported differences between physical models and digital measurements ranging from 0.22 ±0.1 mm to 1.20 ±0.46 mm, and discrepancies between digital and manual measurements ranging from 0.58±0.37 to 0.93±0.36 mm and up to 1.95 ±0.33 mm [17,18, 31-33].

A systematic review by Antonacci et al. [34] assessed the accuracy of face-scanning technologies, focusing on questions regarding the lowest accuracy compared to direct anthropometry, the most affected parameters by the technology used, and on which protocol allows the most clinically accurate scans in daily clinical practice. They concluded that none of the included technologies significantly deviated from direct anthropometry, and the face scans were considered a powerful method for capturing extraoral information and integrating it into a digital workflow. The mean differences in the distances between the considered landmarks range from 1.10 to -1.74 mm, similar to our study. A series of studies conducted by Raffone et al. [35-37] assessed the trueness and precision of low-cost portable face scanners. They concluded that they were reliable devices for clinical use due to excellent precision and effective reduction of motion artifacts [35], and the clinical reliability may be improved by matching multiple face scans using reference points on the face fixed with adhesives [36].

Although the results of the present study is promising, it must still be considered with a bit of caution since only one type of face scanner was evaluated. Furthermore, these results may not be assumed to be similar or consistent in fully-edentate persons. Hence the accuracy in other relevant clinical situations, such as the definition of the VDO in edentulous subjects for

fabrication of digital complete dentures using CAD/CAM technology, needs to be addressed in further purpose-built studies.

## 5. Conclusion

The findings of this study demonstrate that VDO can be measured accurately from face scans using 3D mesh-processing software and that even small changes in the VDO could be detected using the digital methods.

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## 7. Figure Legends

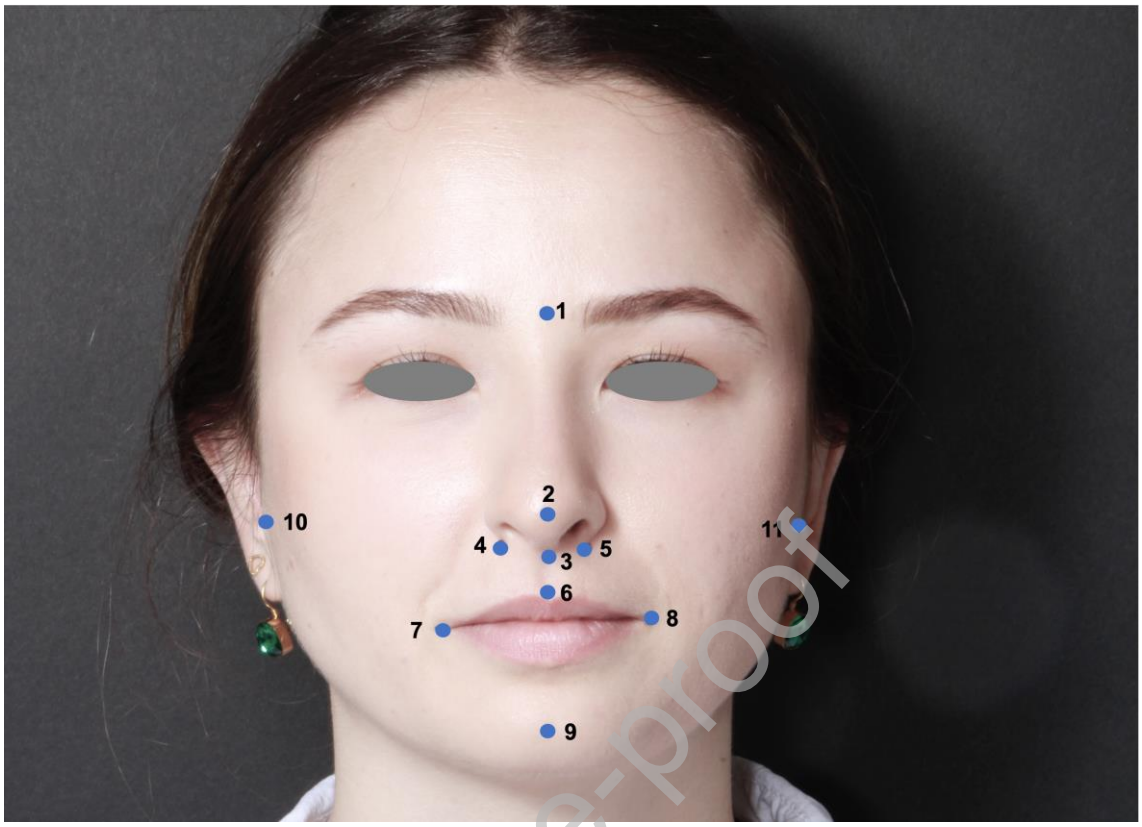


Figure 1 Landmarks on the face used for the measurements, 1- Glabella (G), 2- Pronasale (PrN), 3- Subnasale (SbN), 4- inferior border of the right Alare (AR), 5- inferior border of the left Alare (AL), 6- Labiale superius (Ls), 7- right Cheilion (ChR), 8- left Cheilion (ChL), 9- Soft Pogonion (SPg), 10- Right Tragus of the ear (TrR), and 11- Left Tragus of the ear (TrL).


Figure 2 A typical face scan of a random participant showing the marked landmarks, A- frontal view, B- lateral view.

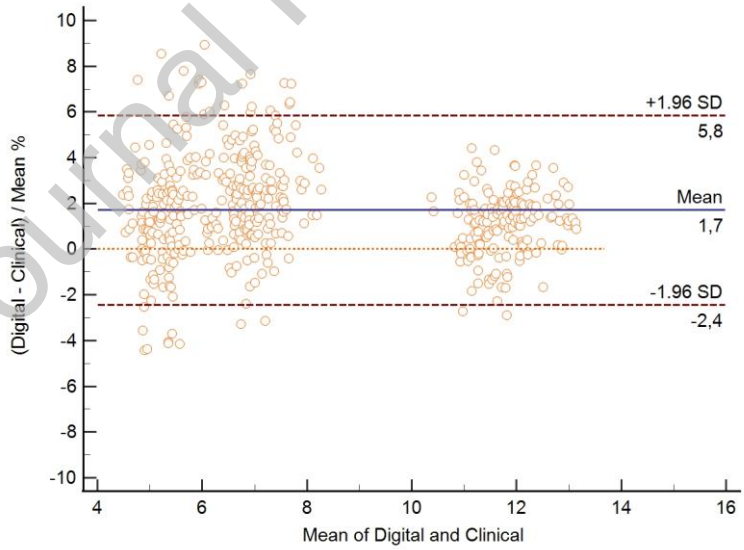


Figure 3. Bland-Altman plot for the comparison between the scanner and clinical methods – vertical measurements.

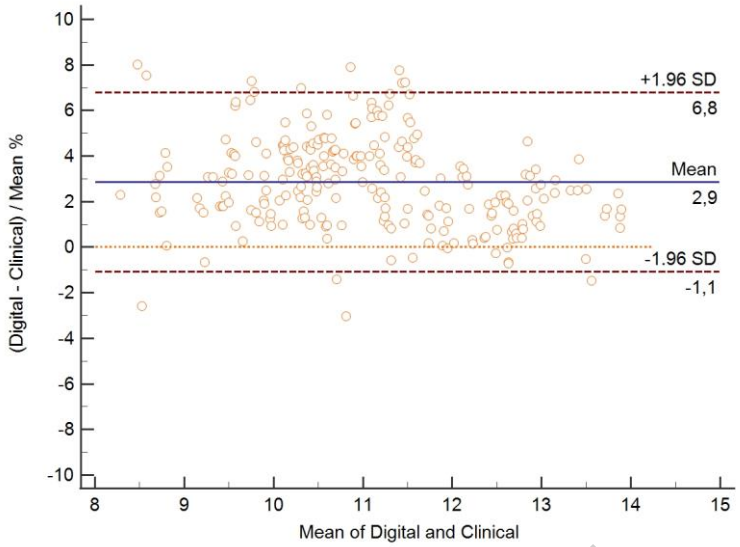


Figure 4. Bland-Altman plot for the comparison between the scanner and clinical methods – horizontal measurements.

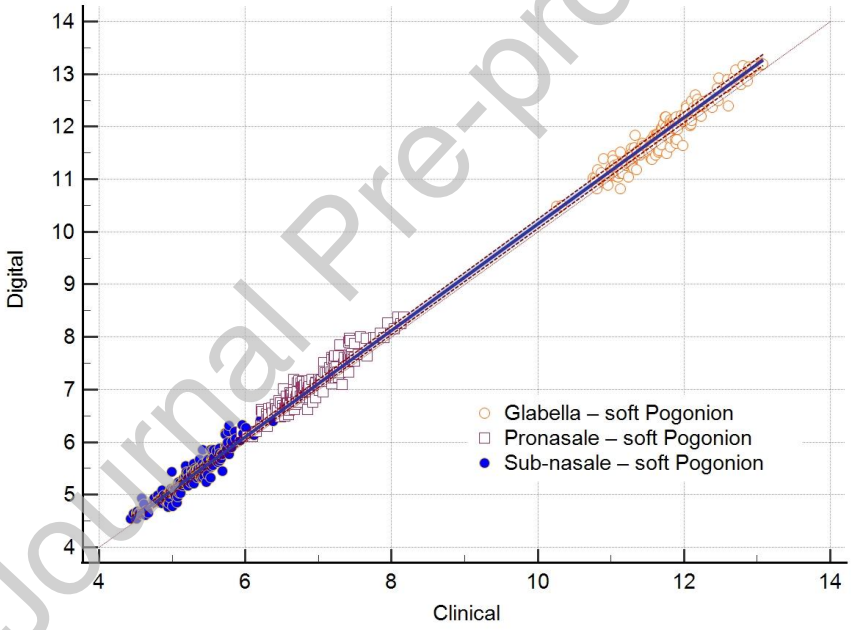


Figure 5. Passing-Bablok regression plots for the vertical measurements, showing the regression line for the observed values (solid line), the confidence interval for the regression line (dashed lines) and identity line (x=y, dotted line).

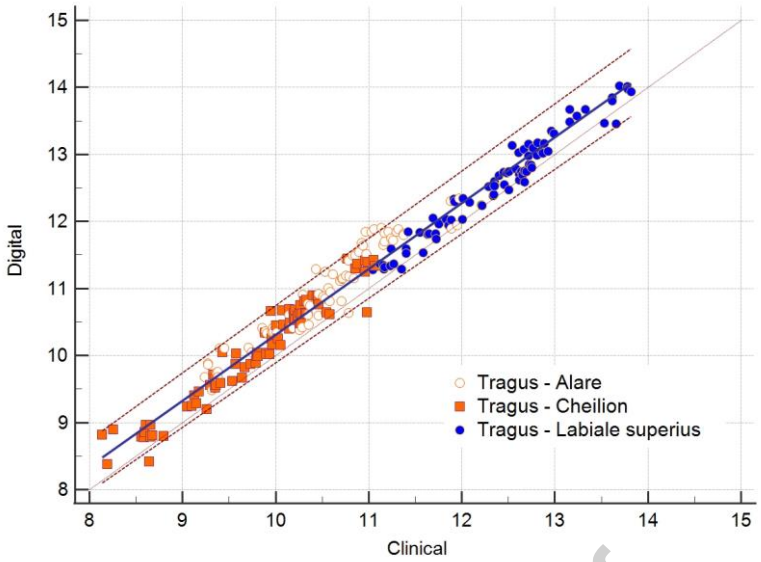


Figure 6. Passing-Bablok regression plots for the horizontal measurements, showing the regression line for the observed values (solid line), the confidence interval for the regression line (dashed lines) and identity line (x=y, dotted line).

Table 1. Paired differences (digital – clinical), according to the measurement points and increased occlusal distance

| Parameters | Occlusal distance | Paired Differences Mean | SD | P=value | r |
|---|---|---|---|---|---|
| Glabella – soft Pogonion | 0 mm | 0.147 | 0.135 | <0.001 | 0.976 |
| | 2 mm | 0.069 | 0.252 | 0.089 | 0.931 |
| | 4 mm | 0.148 | 0.166 | <0.001 | 0.957 |
| | 6 mm | 0.103 | 0.186 | 0.001 | 0.952 |
| Pronasale – soft Pogonion | 0 mm | 0.203 | 0.134 | <0.001 | 0.957 |
| | 2 mm | 0.159 | 0.163 | <0.001 | 0.941 |
| | 4 mm | 0.185 | 0.142 | <0.001 | 0.948 |
| | 6 mm | 0.134 | 0.151 | <0.001 | 0.945 |
| Sub-nasale – soft Pogonion | 0 mm | 0.104 | 0.099 | <0.001 | 0.968 |
| | 2 mm | 0.101 | 0.168 | <0.001 | 0.934 |
| | 4 mm | 0.096 | 0.136 | <0.001 | 0.947 |
| | 6 mm | 0.054 | 0.139 | 0.019 | 0.948 |

| | | | | | |
|---|---|---|---|---|---|
| Tragus – Alare | – | 0.444 | 0.210 | <0.001 | 0.956 |
| Tragus – Cheilion | – | 0.294 | 0.191 | <0.001 | 0.971 |
| Tragus – Labiale superius | – | 0.187 | 0.151 | <0.001 | 0.979 |

Table 2. Intra-class correlation coefficients (ICC) using single-rating, absolute agreement and 2-way random effects model to assess the intra-rater reliability between methods (clinical and digital), and inter-rater reliability.

| | | | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Parameter | ICC (95%CI) | Value | df1 | df2 | p-value |
| Intra-rater (Digital *vs* Clinical) | Overall data | All measurements | 0.997 (0.989 – 0.999) | 1153.6 | 479 | 479 | <0.001 |
| | Overall data | Glabella – soft Pogonion | 0.966 (0.913 – 0.983) | 40.16 | 159 | 159 | <0.001 |
| | | Pronasale – soft Pogonion | 0.943 (0.895 – 0.981) | 38.82 | 159 | 159 | <0.001 |
| | | Sub-nasale – soft Pogonion | 0.962 (0.895 – 0.981) | 36.41 | 159 | 159 | <0.001 |
| | Rater #1 | Glabella – soft Pogonion | 0.945 (0.893 – 0.969) | 41.82 | 79 | 79 | <0.001 |
| | | Pronasale – soft Pogonion | 0.908 (0.754 – 0.966) | 37.99 | 79 | 79 | <0.001 |
| | | Sub-nasale – soft Pogonion | 0.918 (0.770 – 0.962) | 33.19 | 79 | 79 | <0.001 |
| | Rater #2 | Glabella – soft Pogonion | 0.926 (0.732 – 0.969) | 40.85 | 79 | 79 | <0.001 |
| | | Pronasale – soft Pogonion | 0.876 (0.714 – 0.963) | 42.71 | 79 | 79 | <0.001 |
| | | Sub-nasale – soft Pogonion | 0.936 (0.837 – 0.968) | 40.64 | 79 | 79 | <0.001 |
| Interater (Rater #1 *vs* Rater #2) | Clinical | Glabella – soft Pogonion | 0.958 (0.919 – 0.976) | 54.89 | 79 | 79 | <0.001 |
| | | Pronasale – soft Pogonion | 0.941 (0.894 – 0.965) | 37.99 | 79 | 79 | <0.001 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sub-nasale – soft Pogonion | 0,964 (0.944 – 0.977) | 55.03 | 49 | 79 | <0.001 |
| | Digital | Glabella – soft Pogonion | 1.000 (0.999 – 1.000) | 2137.1 | 79 | 79 | <0.001 |
| | | Pronasale – soft Pogonion | 0.999 (0.999 – 1.000) | 1315.6 | 79 | 79 | <0.001 |
| | | Sub-nasale – soft Pogonion | 0.999 (0.999 – 1.000) | 1864.8 | 79 | 79 | <0.001 |
| Intra-rater | Digital *vs* Clinical | Tragus – Alare | 0.976 (0.963 – 0.985) | 42.16 | 79 | 79 | <0.001 |
| | | Tragus – Cheilion | 9.984 (0.975 – 0.990) | 63.15 | 79 | 79 | <0.001 |
| | | Tragus – Labiale superius | 0.989 (0.983 – 0.993) | 94.49 | 79 | 79 | <0.001 |

Table 3. Passing-Bablok regression equations comparing the measurements obtained by the clinical (x-axis) and digital (y-axis) methods.

| | Regression equation | Intercept (95% CI) | Slope (95% CI) | Random difference |
|---|---|---|---|---|
| Vertical measures | y = 0.027 + 1.01 x | 0.027 (-0.01 – 0.07) | 1.01 (1.00 – 1.02) | 0.109 |
| Horizontal measures | y = 0.484 + 0.98 x | 0.484 (0.27 – 0.72) | 0.98 (0.96 – 1.00) | 0.210 |

**Conflicts of interest Statement**

The authors declare that they have no conflict of interests.