Journal of Oral Biology and Craniofacial Research 9 (2019) 331–335

Contents lists available at ScienceDirect

Journal of Oral Biology and Craniofacial Research

journal homepage: www.elsevier.com/locate/jobcr

Scan time, reliability and accuracy of craniofacial measurements using a 3D light scanner☆

Camilla Franco de Sá Gomes, Mylena Ranieri Libdy, David Normando*

Department of Orthodontics, Federal University of Pará, Belem, Pará, Brazil

ARTICLE INFO

Keywords:
Laser scanning
Face validity
Orthodontics
Oral surgery

ABSTRACT

Aim: To evaluate time, reliability and accuracy of craniofacial measurements with a 3D light scanner, considering prior demarcation of surface points on the face.

Materials and methods: Eleven facial measurements of 15 volunteers were obtained by a scanner (Artec Eva TM) and by a caliper directly on the face, with or without demarcation of facial reference points. Inter and intramethod comparison were examined by intraclass correlation coefficient and analysis of random error by the Dahlberg formula. Agreement between the methods was analyzed by the Bland-Altman. A Wilcoxon test was used to compare the time for each method, at $p < 0.05$.

Results: Marking points on the face improved accuracy for both methods. In the inter-methods analysis with landmarks, the scanner showed excellent reliability in all measures ($ICC = 0.92–0.97$, $p < 0.0001$). Measurements accuracy with scanner was around 2 mm when the points were not previously marked and about 1 mm when the points were marked. Measures taken with the scanner, however, took twice as long, compared with the direct method.

Conclusions: Craniofacial measurements obtained with scanner showed excellent reliability and accuracy, which qualifies this method for clinical and scientific use. Accuracy is improved when the points were previously marked on face. However, the time needed to obtain measurements is greater than about 4 min for the direct method.

1. Introduction

Craniofacial anthropometry is a widely used method in dentistry, with applicability in the study of face growth,[1] diagnosis of skeletal discrepancies,[2] and planning and evaluation of the results of orthodontic and ortho-surgical treatment.[3,4]

The conventional technique consists of measurements performed with a caliper directly on the face.[5] This is a simple, noninvasive method that does not require expensive equipment,[6] although it is difficult to apply in clinical practice since the marking points for measurements consume a considerable time. Thus, traditionally, two-dimensional photogrammetry and cephalometry are used as the main sources of craniofacial measurement data. However, the limitations of these techniques to capture the three-dimensional complexity of the human face[7] have been recognized.

In this context, techniques of computerized facial measurements have been suggested to reduce the time spent on examinations and improve the reliability of measurements as well as allow the storage and retrieval of data and information.[2,3] Several studies[6,8–14] aimed to evaluate the reliability of anthropometric measurement with three-dimensional (3D) and two-dimensional (2D) apparatus. One of the methods, digital scanning of the face with light, is performed by means of devices that collect reflected light and images to analyze the depth information and texturing of 3D objects. It is considered a non-invasive method that avoids the compression of skin tissues[15] and does not cause discomfort to the patient.

Despite the reports of the reliability of face measurement methods, it is necessary to examine the time needed, data processing and reliability of the methods regarding the marking of points.

This study aims to assess the accuracy and replicability of a light scanner, plus the scan time. It also examined the accuracy for prior demarcation of surface points on the face.

2. Material and methods

The study was approved by the Ethics in Research Committee

☆ This study was approved under # 1.121.997 by the ethics Committee for Health Science of Federal University of Pará.

* Corresponding author. Rua Boaventura da Silva, 567-1201, Belém, 66055-090, Pará, Brazil.
E-mail addresses: camillafsgomes@gmail.com (C. Franco de Sá Gomes), mylena_libdy@yahoo.com.br (M.R. Libdy), davidnormando@hotmail.com (D. Normando).

https://doi.org/10.1016/j.jobcr.2019.07.001
Received 12 February 2019; Received in revised form 1 July 2019; Accepted 6 July 2019
Available online 07 July 2019
2212-4268/

number XXX. Participants signed an informed consent form. Authors do not have ant conflict of interest. We have used a handheld 3D light scanner (Artec Eva TM, Artec Group, Luxembourg) that can make a quick, textures and accurate 3D model of medium sized objects. Capturing and simultaneously processing up to two million points per second with na high accuracy— up to 0.1 mm.

The accuracy and reliability of face measurements obtained with the scanner were compared to measurements obtained directly from the face using a digital caliper (Agro, Industry and Commerce, São Paulo, Brazil) with a 0.1 mm resolution. One previously trained operator performed the landmarks, measurements and the scanning. Meanwhile, as the operator scans the volunteer's face, the 3D image was automatically generated in the software Artec Studio (Artec Group, Luxembourg), where it was possible to manipulate the model, as well created a database.

The sample size calculation was based on a previous study[16] and includes 15 adults—6 females and 9 males—with a mean age of 25 years (SD = 1.1 years). No subjects had undergone facial surgery or had a history of craniofacial trauma and/or congenital abnormalities. Each volunteer was subjected to both methods: direct anthropometry and face scanning. For both techniques, the volunteer was seated in a comfortable position with their eyes closed and remained immobile during the process to avoid jeopardizing the achievement of the measures (Fig. 1).

It was necessary to perform two facial scans, one without the prior appointment of the reference points and another after marking for measurement of linear distances.

The next step was to obtain measurements with the caliper. Then the reference points were made on the face, and a new scan and direct measurement were performed. Eleven linear measurements (Fig. 2) were obtained with and without the prior appointment of reference points on the soft tissues of the face (Fig. 3). The points were marked with black liquid eyeliner as described in a previous study.[16]

The following linear measurements were obtained from the points (Fig. 2):

- N–Sn: linear distance from point N (nasion) to point Sn (subnasal).
- N–Me: linear distance from point N (nasion) to point Me (mentonian).
- Sn–Me: linear distance from point Sn (subnasal) to point Me (mentonian).
- $Ex_r - Ex_l$: linear distance from point Ex_r (exocanthion right) to point Ex_e (exocanthion left).
- $Ch_r - Ch_l$: linear distance from point Ch_r (cheilion right) to point Ch_l (cheilon left).
- Pg– T_r: linear distance from point Pg (pogonion) to point T_r (tragus right).
- Pg– T_l: linear distance from point Pg (pogonion) to point T_l (tragus left).
- Pg– Go_r: linear distance from point Pg (pogonion) to point Go_r (gonion right).
- Pg– Go_l: linear distance from point Pg (pogonion) to point Go_l (gonion left).
- Sn-Ls: linear distance from point Sn (subnasal) to point Ls (upper lip).
- Me–Li: linear distance from point Me (menton) to point Li (lower lip).

Fig. 1. Voluntary positioning for obtaining a scan of the face.

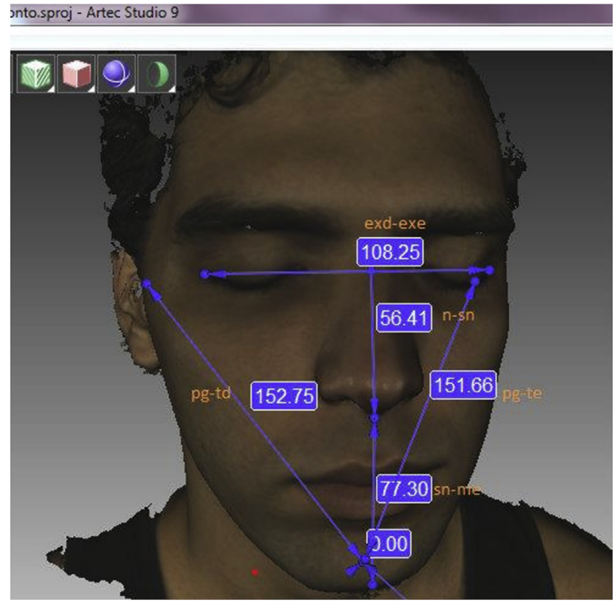

Fig. 2. Obtaining of linear measurements of the face measured in a digital model further processed to scan the face.

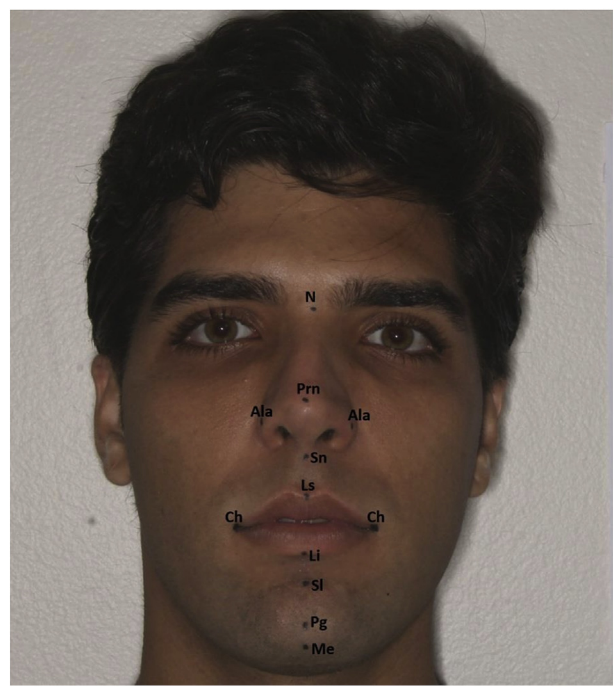

Fig. 3. Marking the reference points on the face with liquid eyeliner.

2.1. Methods of time analysis

A stopwatch recorded the total time needed to execute the method and process the data. The time needed to mark points on the face was considered the same for both techniques and was added to the subsequent time according to the specific method of measurement. For the scanner, two times were obtained: first the duration of the face scan and then the time needed to obtain digital models and linear measurements on the computer. In the direct method, the amount of time needed to obtain measurements with a digital caliper was recorded.

2.2. Statistical analysis

D'Agostino statistical test was used to analyze the normality of the data. To conduct intra- and inter-method analysis of the reproducibility of measurements, we used intraclass correlation coefficient (ICC). Wilcoxon test was used for time analysis, as the data had a non-normal distribution. Analyses were made by BioEstat 5.3 program (Mamirauá Institute, Belém, Pará, Brazil) at $p < 0.05$. The Dahlberg formula was used for analysis of random error. For inter-methods agreement, we plotted a Bland-Altman scatter plot using MedCalc software, version 9.3 (MedCalc Software, Mariakerke, Belgium).

3. Results

Comparing each method with or without previous points demarked on the face, the accuracy was more reliable for measures Sn-Ls, Me–Li, N-SN and Chd-Che in both methods, since they showed the least difference between the means values and the smallest random errors, around 1 mm. The measures that included soft pogonion landmark (Pg-GoL, Pg-GoR, Pg-TR and Pg-TL) denoted less precision, with random error around 3–4 mm for both methods (Table 1). Also, these variables encompassing Go point showed a moderate reliability (ICC), while all others variables showed a good to excellent reliability. Overall reliability was similar for both methods regardless the presence of marked points (Table 1).

Overall inter-methods accuracy was around doubled improved when the landmarks were previously marked, mainly for those variables involving Go point (Pg-GoR and Pg-GoL). Considering the measurement of the variables with previously marked points, inter-method analysis (direct anthropometry vs scanner) showed the worst accuracy when Pg point is included in the measure being evaluated, around 1–2 mm (Table 2). However, this accuracy seems enough reliable to scientific and clinical purpose.

Also ICC is improved significantly when comparing inter-method analysis with the marking points. While five variables (Me–Li, Sn-Ls, Pg-GoR, Pg-GoL, N–Sn) showed a moderate to good realibility when inter-method is evaluated, intraclass correlation between measurements obtained by the methods with marking points, showed excellent replicability (Table 2).

For scanning validation as a reliable method of facial measurement with points, we conducted a Bland-Altman analysis through a scatter plot (Table 2). All linear measurements showed moderate individual variability of agreement between the two instruments (scanner and caliper). The differences between averages of the methods in N–Sn, N–Me, Chd-Che and Sn-Ls were lower than for the other measures, demonstrating less variability, making facial scanner with points the most reliable method for these measurements (Table 2). However, the majority of research subjects remained within two standard deviations of difference.

In general, estimates of absolute magnitude of intra- and inter-methods error tended to be higher in the variables of greatest dimensions (Pg-TL, Pg-TR, Pg-GoR and Pg-GoL). Thus, smaller absolute magnitude errors were associated with variables of lower value (Sn-Ls, Me–Li and ChL-ChR). The intra-method error relative to the caliper had a breadth of 0.99–4.42 mm compared to 0.82–3.27 mm for the scanner (Table 1). In the inter-method analysis, the error amplitude without points was 0.65 a 2.16 mm, and that of tagging points on the face was 0.85–6.22 mm (Table 2).

It was also noticed that the differences between means of measures taken directly on the face and those obtained by scanning were negative, showing that the measurements obtained by scanner were slightly larger than those obtained by direct technique (Table 2).

A statistically significant difference ($p < 0,005$) was found for intra- and inter-methods time analysis. The results showed that the method that consumed the least time was the direct technique without marking the reference facial points, which took a median of 3′05″, while scanning without marking points consumed more time (8′19″) (Table 3).

Table 1
Mean, difference of means, random error (Dahlberg) and Intraclass correlation (ICC) for intra-method analysis of the face measurements in the direct technique (caliper) and 3D scanner.

	Direct measurement (caliper)							3D Scanner						
	Mean							Mean						
Variables	W/out point	With point	Difference X1-X2		Random error		ICC p-value	W/out point	With point	Difference X3-X4		Random error		ICC p-value
(mm)	X1	X2	mm	(%)	mm	(%)		X3	X4	mm	(%)	mm	(%)	
N–Sn	53,64	53,15	0,49	0,92	1,23	2.30	0,88***	51,62	53,73	−2,11	−4,01	1,89	3.59	0,73**
N–Me	117,74	115,34	2,4	2,06	2,47	2.12	0,86***	114,88	116,53	−1,65	−1,43	2,01	1.74	0,91***
Sn–Me	64,74	63,71	1,03	1,60	1,71	2.66	0,87***	64,99	64,28	0,71	1,10	1,76	2.72	0,87***
ExR-ExL	98,96	98,17	0,79	0,60	1,77	1.35	0,94***	97,14	99,18	−2,04	−2,08	1,87	1.91	0,93***
ChR-ChL	50,97	51,15	−0,18	−0,35	0,99	1.94	0,89***	50,87	52,03	−1,16	−2,.25	1,41	2.74	0,86***
Pg-TR	141,96	143,86	−1,9	−1,33	2,01	1.41	0,92***	144,13	146,54	−2,41	−1.66	2,06	1.42	0,93***
Pg-TL	141,52	143,08	−1,56	−1,10	1,88	1.32	0,93***	142,88	144,73	−1,85	−1.29	2,08	1.45	0,93***
Pg-GoR	101,27	97,60	3,67	3,69	4,42	4.45	0,45*	99,69	99,02	0,67	0.67	3,27	3.29	0,74**
Pg-GoL	101,40	96,47	4,93	4,98	4,28	4.33	0,47*	98,98	97,65	1,33	1.35	3,27	3.33	0,75**
Sn-Ls	13,56	13,66	−0,1	−0,73	1,20	8.82	0,83***	14,95	14,31	0,64	4.37	0,82	5.60	0,89***
Me–Li	34,11	33,36	0,75	2,22	1,25	3.71	0,84***	34,05	33,74	0,31	0.91	1,73	5.10	0,71*

***p < 0,05 **p < 0,001 ***p < 0,0001.**
Realibility: ICC < 0,4 (Poor) 0,4 ≤ ICC < 0,75 (medium to good) ICC ≥ 0,75 (excellent).

Table 2
Mean, standard deviation (SD), difference of means, random error (Dahlberg) and Intraclass correlation (ICC) and Bland-Altman statistics for inter-methods analysis of the face measurements in the direct technique (caliper) and 3D scanner.

	Without points					With points					Bland-Altman	
Variables	Difference X1-X3		Random error		ICC p-value	Difference X2-X4		Random error		ICC p-value	Direct x 3D with points	
(mm)		(%)		(%)			(%)		(%)		X	2SDs
N–Sn	2,02	3.84	2,09	3.97	0,62*	−0,58	−1.09	0,90	1.68	0,94***	−0,6	1,7 — -2,9
N–Me	2,86	2.46	2,89	2.48	0,82***	−1,19	−1.03	1,00	0.86	0,97***	−1,20	0,37 — -2,77
Sn–Me	−0,25	−0.39	1,90	2.93	0,85***	−0,57	−0.89	1,04	1.63	0,94***	−0,6	2,2 — -3,4
ExR-ExL	1,82	1.86	1,75	1.78	0,94***	−1,01	−1.02	0,84	0.85	0,98***	−1,00	0,32 — -2,33
ChR-ChL	0,1	0.20	1,30	2.55	0,86***	−0,88	−1.71	1,03	2.00	0,94***	−0,9	1,5 — -3,2
Pg-TR	−2,17	−1.52	2,22	1.55	0,90***	−2,68	−1.85	2,16	1.49	0,92***	−2,7	0,3 — -5,7
Pg-TL	−1,36	−0.96	1,52	1.07	0,94***	−1,65	−1.15	1,65	1.15	0,95***	−1,7	1,7 — -5,0
Pg-GoR	1,58	1,57	3,41	3.39	0,66*	−1,32	−1.34	1,19	1.21	0,96***	−1,42	0,46 — -3,30
Pg-GoL	2,42	2,42	3,60	3.59	0,60*	−1,18	−1.22	1,09	1.12	0,97***	−1,19	0,84 — -3,21
Sn-Ls	−1,39	−9,75	1,35	9.47	0,72**	−0,65	−4,65	0,87	6.22	0,91***	−0,6	1,5 — -2,8
Me–Li	0,06	0,18	1,81	5.31	0,67*	−0,38	−1,13	0,65	1.94	0,96***	−0,38	1,32 — -2,08

*p < 0,05 **p < 0,001 ***p < 0,0001.
Realibility: ICC < 0,4 (Poor) 0,4 ≤ ICC < 0,75 (medium to good) ICC ≥ 0,75 (excellent).
"Difference X1-X3": diference between measures obtained with caliper without points (X1) and scanner without points (X3).
"Difference X2-X4": difference between measures obtained with caliper with point (X2) and scanner with point(X4).

4. Discussion

Traditionally, anthropometry is performed directly by pachymetry and tapes for the measurement of the body.[18,19] However, this has several limitations, such as data storage,[20] time spent with the patient and lack of practicality. Thus, various studies are being conducted with the objective of validating the latest modern techniques of anthropometry,[19,20] which include use of scanners and software.

The advancement of technology has made it possible to perform anthropometric measurements indirectly to obtain colored and textured digital 3D models. However, to validate this method, we aimed to ensure that it provides reliability in quantifying the soft tissue of the face.[19,21–24] This study suggests that face scanning is a reliable method of measurement, since the results showed excellent replicability intra and inter-method for unmarked points and points in most of the 11 measures examined, corroborating previous studies.[25,26]

From the Bland-Altman analysis, we observed that both techniques have a good agreement, which allows us to validate the scanner as a reliable method. For all measurements we observed a moderate individual variability, as should approach the average as much as possible, yet most individuals remained between the confidence intervals and the difference was of no clinical importance.

Although Pg-Td, Pg -Te, Pg-God and Pg-Goe presented a high correlation coefficient (0.92, 0.95, 0.96, 0.97, respectively) in the inter-method analysis with the prior appointment dots (Table 2), demonstrating only moderate concordance on the scatter plot because it presented greater amplitude between the confidence intervals, which makes it the least reliable method for these measures.

The points on the face contributed to an increase of accuracy[5,19] in the anthropometry by scanning, and this should be performed prior to the scan.[18] Because they become more difficult to identify in digital models, the operator should be well trained and calibrated to locate them. However, it would be unfeasible to consider making these points in certain populations, such as indigenous communities, which have a cultural practice of painting their bodies.

However, the analysis of the results showed that the measures that included the Gonion point (Pg-God and Pg-Goe) had the biggest rates of error when the point was not previously marked. The error was associated with the fact that this point is difficult to find because it is located where the mandible branch bisects its base.[27]

It was observed that the random error ranged from 1.30 mm to 3.60 mm for measurements without the demarcation of the points and from 0.65 mm to 2.16 mm when the points were previously defined (Table 2). However, the marking of points was performed only once on the face for execution of both techniques, and only inter-methods replicability can be evaluated.

Through intra-method random error analysis of the direct technique (2.11 mm) and scanner (2.01 mm), we observed similarity of both techniques. In the inter-method analysis with the marker points, we found that the scan showed measures slightly larger than the direct method (average scanner: 83.7 mm; average caliper: 82.6 mm), which in turn may be related to compression of the soft tissue of the face at the time of identifying the point by caliper. The literature presents a controversy on this issue, since some authors have found higher measures with scanners[28] while others[29] have found the opposite. The contradiction of the results can be associated with the intrinsic properties of each type of scanner and the operator's training in placing the measures directly on the face.

In this study it was verified that when we perform the marking of points on the face before the scan there is a reduction in the time needed to accomplish the measures (4′18″ without the marking points to 2′49″ with marker points). Obtaining linear measures becomes much faster with the reference points because the operators do not need to identify them in the software, especially the structures considered more

Table 3
Median time analysis (minutes) for the execution of direct techniques (caliper) and scanning and intra- and inter-method p-values (Wilcoxon).

	Caliper			Scanner 3D			Caliper x Scanner 3D
	With point	Without Point	p value	With point	Without Point	p value	p value
Median time (minutes)	5′03″	3′05″	0,0003**	7′18″	8′19″	0,017*	0,0003**

*p < 0,05 **p < 0,001 ***p < 0,0001.

difficult to identify, such as the gonion[27] and pogonion.

Previous studies[5,13,19] analyzed the time needed to scan and obtain three-dimensional images, but did not conduct a comparative analysis of this with the duration of the direct technique. Some authors consider scanning a faster method because they do not consider the time needed to process the image and obtain measurements by the program. In this research, we observed a statistically significant difference between the methods, since the scanner consumed more time (about 4 min) compared to the direct technique. In view of this, it is necessary to greatly advance scanner technology to provide faster image obtainment and processing. However, this system has the great advantage of the storage and export of data, the possibility of analyzing the 3D models for case planning[15,30] and the creation of a database for conducting longitudinal surveys.

A profound knowledge of facial asymmetry is essential to critically analyse all the features involved, and accurately quantify the magnitude of disproportion. This would help formulate more satisfying treatment plan in terms of optimizing esthetics and function while taking into consideration the perceptions and expectations of the patient.[31]

5. Conclusions

Craniofacial measurements obtained with scanner showed excellent reliability and accuracy, which qualifies this method for clinical and scientific use. Accuracy is improved when the points were previously marked on face. However, the time needed to obtain measurements is greater than about 4 min for the direct method.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobcr.2019.07.001.

References

1. Kau CH, Zhurov A, Bibb R, Hunter L, Richmond S. The investigation of the changing facial appearance of identical twins employing a threedimensional laser imaging system. *Orthod Craniofac Res.* 2005;8:85–90.
2. Hammond P. The use of 3D face shape modeling in dysmorphology. *Arch Dis Child.* 2007;92:1120–1126.
3. Douglas TS. Image processing for craniofacial landmark identification and measurement: a review of photogrammetry and cephalometry. *Comput Med Imag Graph.* 2004 Oct;28(7):401–409.
4. Hajeer MY, Mao Z, Millett DT, Ayoub AF, Siebert JP. A new three-dimensional method of assessing facial volumetric changes after orthognathic treatment. *Cleft Palate Craniofac J.* 2005;42:113–120.
5. Weinberg SM, Scott NM, Neiswanger K, Brandon CA, Marazita ML. Digital three-dimensional photogrammetry: evaluation of anthropometric precision and accuracy using a genex 3D camera system. *Cleft Palate Craniofac J.* 2004;41(5):507–518.
6. Allanson JE. Objective techniques for craniofacial assessment:what are the choices? *Am J Med Genet.* 1997;70:1–5.
7. Altobelli DE. Computer-assisted acquisition of facial surface topography. In: Farkas LG, ed. *Anthropometry of the Head and Face.* New York: Raven Press; 1994:219–234.
8. Winder RJ, Darvann TA, McKnight W, Magee JDM, Ramsay-Baggs P. Technical validation of the Di3D stereophotogrammetry surface imaging system. *Br J Oral Maxillofac Surg.* 2008 Jan;46(1):33–37.
9. Ozsoy U, Demirel BM, Yildirim FB, Ozgur T, Sarikcioglu L. Method selection in craniofacial measurements: advantages and disadvantages of 3D digitization method. *J Cranio-Maxillo-Fac Surg.* 2009;37:285–290.
10. Ghoddousi H, Edler R, Haers P, Wertheim D, Greenhill D. Comparison of three methods of facial measurement. *J Oral Maxillofac Surg.* 2007;36:250–258.
11. Guyot L, Dubuc M, Ric1211QAhard O, Philip N, Dutour O. Comparison between direct clinical and digital photogrammetric measurements in patients with 22q11 microdeletion. *Int J Oral Maxillofac Surg.* 2003;32:246–252.
12. Wong JY, Albert K, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. *Cleft Palate Craniofac J May.* 2008;45(3):232–239.
13. Kook MS, Jung S, Park HJ, et al. A comparison study of different facial soft tissue analysis methods. *J Cranio-Maxillo-Fac Surg.* 2014;42:648–656.
14. Li G, Wei J, Wang X, et al. Three-dimensional facial anthropometry of unilateral cleft lip infants with a structured light scanning system. *J Plast Reconstr Aesthet Surg.* 2013;66:1109–1116.
15. De Menezes M, Sforza C. Facial three-dimensional (3D) morphometry. *Dental Press J Orthod.* 2010 Jan/Feb;15(1):13–15.
16. De Menezes M, Rosatia R, Allievia C, Sforzab C. A photographic system for the three-dimensional study of facial morphology. *Angle Orthod.* 2009;79(6):1070–1077.
18. Wang MJ, Wu WY, Lin KC, Yang SN, Lu JM. Automated anthropometric data collection from three-dimensional digital human models. *Int J Adv Manuf Technol.* 2007;32(1):109–115.
19. Bush K, Antonyshyn O. Three-dimensional facial anthropometry using a laser surface scanner: validation of the technique. *Plast Reconstr Surg.* 1996 Aug;98(2):226–235.
20. Kharnbay B, Nairn N, Bell A, Miller J, Bowman A, Ayoub Af. Validation and reproducibility of a high-resolution three-dimensional facial imaging system. *Br J Oral Maxillofac Surg.* 2008 Jan;46(1):27–32.
21. Ramieri GA, Spada MC, Nasi A, et al. Reconstruction of facial morphology from laser scanned data. Part I: reliability of the technique. *Dentomaxillofacial Radiol.* 2006;35:158–164.
22. Galantucci LM, Lavecchia F, Percoco G, Raspatelli S. New method to calibrate and validate a high-resolution 3D scanner, based on photogrammetry. *Precis Eng.* 2014;38:279–291.
23. Hironaga N, Hagiwara K, Ogata K, Hayamizu M, Urakawa T, Tobimatsu S. Proposal for a new MEG–MRI co-registration: a 3D laser scanner system. *Clin Neurophysiol.* 2014;125:2404–2412.
24. Fink M, Medelnik J, Strobel K, Hirschfelder U, Hofmann E. Metric precision via soft-tissue landmarks in three-dimensional structured-light scans of human faces. *J Orofac Orthop.* 2014 Mar;75(2):133–143.
25. Baca DB, Deutsch CK, D'Agostino RB. Correspondence between direct anthropometry and structured light digital measurement. In: Farkas LG, ed. *Anthropometry of the Head and Face.* New York: Raven Press; 1994:235–237.
26. Secher JJ, Darvann TA, Pinholt EM. Accuracy and reproducibility of the DAVID SLS-2 scanner in three-dimensional facial imaging. *J Cranio-Maxillo-Fac Surg.* 2017 Oct;45(10):1662–1670.
27. Campomanes-Álvarez B, Ibáñez O, Navarro F, Alemán I, Cordón O, Damas S. Dispersion assessment in the location of facial landmarks on photographs. *Int J Leg Med.* 2015;129(1):227–236.
28. Aung SC, Ngim RCK, Lee ST. Evaluation of the laser surface scanner as a measuring tool and its accuracy compared with direct facial anthropometricmeasurements. *Br J Plast Surg.* 1995;48:551–558.
29. Farkas LG, Bryson W, Klotz J. Is photogrammetry of the face reliable? *Plast Reconstr Surg.* 1980;66:346–355.
30. Menezes M, Rosati R, Ferrario VF, Sforza C. Accuracy and reproducibility of a 3-dimensional stereophotogrammetric imaging System. *J Oral Maxillofac Surg.* 2010;68:2129–2135.
31. Srivastava D, Singh H, Mishra S, Sharma P, Kapoor P, Chandra L. Facial asymmetry revisited: Part I- diagnosis and treatment planning. *J Oral Biol Craniofac Res.* 2018 Jan-Apr;8(1):7–14. https://doi.org/10.1016/j.jobcr.2017.04.010 Epub 2017 May 15.