Volume Measurements of the External Nose for Anthropometric Purposes: A Comparison between Stereophotogrammetry and Laser Scanner

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Abstract

Three-dimensional (3D) optical imaging technologies for the anthropometric study of superficial soft tissues are widely used nowadays, particularly stereophotogrammetry and laser scanning. Different instruments have been validated for the assessment of linear measurements, angles, and surfaces, proving to be interchangeable. However, despite the growing interest in the volumetric calculation of craniofacial structures, no studies have evaluated the agreement in calculating the volume of 3D models of external facial structures obtained with instruments based on diverse technologies.

This preliminary study compared the volumetric measurements of external nasal casts scanned with optical systems based on stereophotogrammetry and laser scanning to verify their interchangeability in volume assessment. Specifically, 23 nasal casts were scanned with the Vectra M3 (Canfield Scientific Inc, Parsippany, NJ) and the Dental Wings 3Series (Dental Wings Inc, Montreal, Canada). The volume was calculated for the right and left nasal side on each 3D model using the Vectra Analysis Module (VAM, version 7.4.6). The protocol entails the digitization of specific anthropometric landmarks (median: nasion, pronasale, subnasale; paired: subalare, alar curvature, endocanthion) that are also used to select the surface of the nasal side for which the volume has to be calculated. The selected surface is then projected onto a virtual plane passing through the median landmarks to obtain a closed structure for which the volume is automatically calculated by the software. The protocol was applied to all nasal casts, resulting in a total of 92 volumetric measurements. The intra- and inter-operator reliability was evaluated using the Intraclass Correlation Coefficient (ICC). The agreement between the volumetric measurements calculated on the 3D nasal casts acquired with the two devices was verified by Lin's Concordance Correlation Coefficient (CCC) and Passing-Bablok regression.

The ICCs for intra- and inter-operator repeatability proved to be "excellent" (ICC_{Intra} = 0.98; ICC_{Inter} = 0.94). The results of Lin's CCC and Passing-Bablok regression confirmed the interchangeability of the two systems in the volumetric calculation. The Lin's CCC value was ρ = 0.99 with the lower border of 95% CI equals to 0.98, interpretable as "substantial agreement". The Passing-Bablok regression equation was: $y = 1.00x - 0.04$ where the 95% CI for the slope $(95\%\, CI: 0.96 - 1.06)$ and the intercept $(95\%\, CI: -0.65 - 0.44)$ respectively included 1 and 0, allowing to state that no significant differences between the volumes of nose scanned with the two instruments exist.

In conclusion, nasal volumes can be reliably and interchangeably evaluated in 3D models acquired with different optical surface devices, as previously described for linear measurements, angles, and areas. This opens the possibility to interchangeably use different instruments for the volumetric characterization of the external nose. Further studies should evaluate volumes of external facial structures in living subjects and focus on verifying the agreement between different protocols of data collection and analysis.

Keywords: Stereophotogrammetry, Laser Scanning, Volume, Nose, Methodology

1. Introduction

The anthropometric analysis of the human face refers to the measurement and analysis of the dimensions, proportions, and features of the craniofacial complex [1], [2]. Differences in relative size, shape and spatial arrangement between the various facial structures make each human face unique [3]. Indeed, facial anthropometry quantitatively assesses facial parameters to study the variability and characteristics of the face and its structures as their morphology is influenced by several factors as genetics [3], [4], [5], [6], environment [6], [7], health status [8], [9], [10], sex [11], [12], [13], [14], [15], [16], age [12], [13], [17], [18], [19], and biogeographical origins [16], [20], [21], [22].

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The accurate assessment and reliable measurements of craniomaxillofacial structures is of paramount importance in a range of disciplines as anatomy, dentistry, maxillofacial surgery, plastic and reconstructive surgery and clinical dysmorphology, each with its own application [11], [23], [24].
Historically, anthropometric measurements were manually performed by means of the so-called "direct anthropometry" which used instruments as calipers, measuring tapes, stadiometers, anthropometers and goniometers [1]. The advent of three-dimensional (3D) optical imaging technology revolutionized the field of anthropometry and the disciplines in which was applied, thus surpassing 2D imaging methods and the conventional anthropometry [25], [26], [27]. Three-dimensional optical systems offer highly accurate, fast and non-invasive methods to three-dimensionally reproduce an object and to obtain detailed measurements of the superficial facial soft tissues [26], [27]. The most widely used three-dimensional technologies are stereophotogrammetry and laser scanning [28], and some authors argue that these 3D scanning technologies have become the gold-standard for the anthropometric evaluation of the facial soft tissues, particularly stereophotogrammetry [29]. Because of the increasing use of these instruments in the clinical and research field [30], [31], and the number of instruments constantly released on the market [32], it is of paramount importance that these instruments provide equal results with non-clinically relevant differences, thus requiring much effort from researchers in proving the validity, reliability, interchangeability and effectiveness of the used instruments [33].
Three-dimensional comparative studies have been performed for validating stereophotogrammetry and laser scanning in respect to direct anthropometry [34], [35], [36], [37]. In particular, several studies have verified the validity of linear [38], [39], [40], [41], angular [40], [42], and surface distances [40], [43], [44]. However, no comparative studies have focused on volumetric measures, particularly concerning their possible equivalence whether calculated in 3D digital models acquired by different instruments. Nonetheless, volumetric measurements are gaining relevance in the anthropometric evaluation of the facial soft tissues, as they provide a more comprehensive understanding of the craniofacial structural variations and anomalies in a three-dimensional framework, and so more insights rather than unidimensional and bidimensional measurements [33], [45], [46]. This is particularly relevant in disciplines as maxillofacial surgery and dentistry or plastic and reconstructive surgery, where precise volume calculations are critical for the correct planning and evaluation of surgical intervention [45], [47], [48], [49], [50]. In these perspectives, the present study presents a comparative analysis of the nasal volumetric measurements calculated on 3D digital models acquired using two different 3D imaging systems: the Vectra M3, a stereophotogrammetric instrument, and the Dental Wings 3Series, a laser scanning device. The aim is to verify the interchangeability of these two scanning technologies for the volumetric assessment of the external nose.

2. Methods

2.1. Sample and ethics

The study sample of the retrospective study here presented were originally obtained for a previous investigation [51], and the involved subjects gave their consent in the participation after being informed about the procedures. The study sample consisted of 23 well preserved plaster casts of the external nose representative of an adult (> 18 years old) Caucasoid healthy population of both sexes.

2.2. Three-dimensional scan and volume measurements

The plaster casts of the external nose, as previously mentioned, were obtained for a previous investigation and a detailed explanation of the protocol to obtain the nasal casts can be found in the original study of Ferrario et al. [51].
The 23 nasal casts were scanned with two three-dimensional optical systems based on a different technology: the Vectra M3 (Canfield Scientific Inc, Parsippany, NJ), a stereophotogrammetric system with a reported accuracy of 1.2 mm, and the Dental Wings 3Series (Dental Wings Inc, Montreal, Canada), a laser scanning-based dentistry instrument with a reported accuracy of 15 μm. An example of the 3D digital nasal models acquired by the two instruments is depicted in Figure 1.
Before any scanning, the nostrils were closed with wax to avoid 3D artifacts due to hollowed areas.

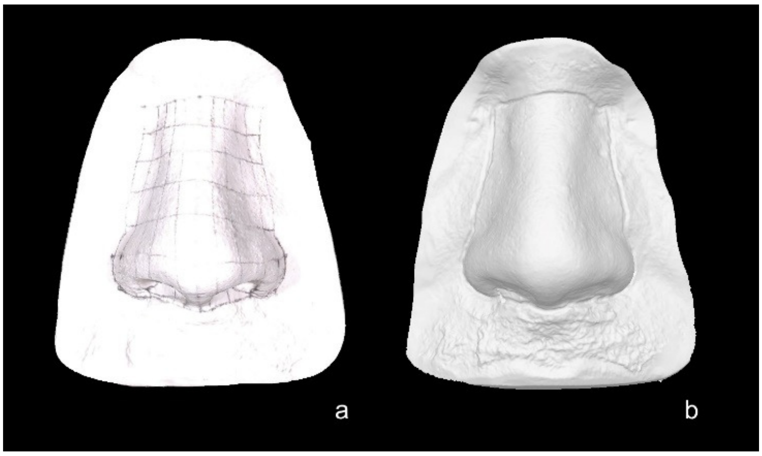

Fig. 1. Example of three-dimensional scansion of the same casts obtained with (a) stereophotogrammetry and (b) laser scanner

The entire protocol for the volume calculation was performed on the Vectra Analysis Module (VAM; version 7.4.6), the software associated with the Vectra M3 system. The first step of the protocol entails the digitization of nine anthropometric landmarks, and specifically three median (nasion, pronasale and subnasale) and three paired bilateral (subalare, alar curvature, endocanthion). The landmarks used are defined in Table 1, and their localization shown in Figure 2.

Table 1. Definition of the digitized anthropometric landmarks

Unpaired median landmarks		
Name	Abbreviation	Definition
Nasion	n	The midline point at the level of the nasal root in correspondence of the nasofrontal suture
Pronasale	prn	The most prominent midline point of the *apex nasi*
Subnasale	sn	The lowest midpoint of the columella where the lower border of the nose and the surface of the upper lip meet
Paired bilateral landmarks		
Endocanthion	en	The point at the inner commissure of the eye fissure
Alar crest	ac	The most lateral point at the level of the root of the nasal ala
Subalare	sbal	The point of the labial insertion of the alar base

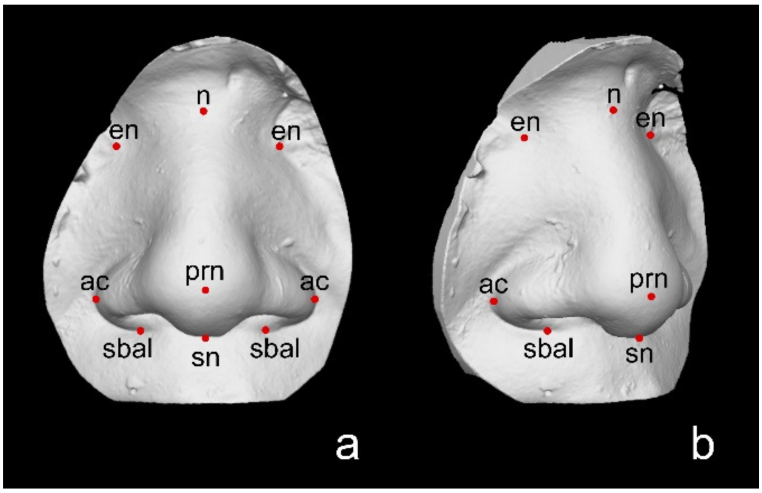

Fig. 2. Landmarks localization on the (a) frontal and (b) right lateral view

As second step of the protocol, the digitized landmarks were used to orient the casts in the three-dimensional space: the three median landmarks were made to pass through the y-axis. Additionally, the landmarks were used to subsequently select the area where to calculate the volume. Indeed, in this study, the volume of each side of the nose, right and left, was calculated.

The third step involved the actual volume calculation that required to import a virtual plane in the working spatial environment. The plane was previously created on Blender [52], and oriented so that its center corresponded to the origin of the three axes, and it coincided with the *zy* plane with equation $x = 0$. The median landmarks were then projected onto the imported virtual plane since through three non-collinear points only one plane exists. The projected landmarks were used to register the virtual plane to pass through the median landmarks of the external nose. At this point, the surface of interest was selected using the median landmarks and the side-specific bilateral landmarks, and the selected surface of the right/left side of the nose was projected onto the plane to close the three-dimensional structure on which to calculate the volume. The volume was calculated automatically by the VAM software through the function "volume of closed surface". All steps included in the protocol for the volumetric calculation are depicted in Figure 3.
Finally, a total of 92 bilateral volumetric measurements were obtained: 46 for the three-dimensional models obtained with the stereophotogrammetric instruments, and 46 for the three-dimensional models obtained with the laser scanner.

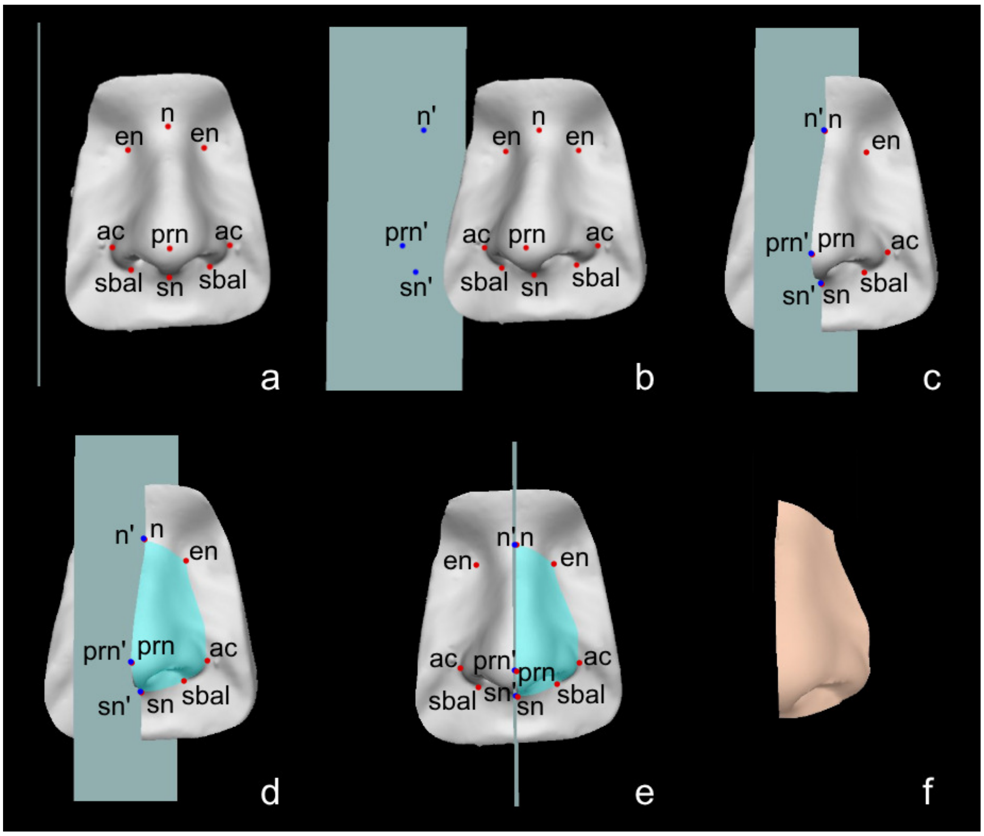

Fig. 3. Steps of the protocol of volume calculation. (a) Opening of the 3D model and import of the virtual plane; (b) projection of the median landmarks on the plane; (c) registration of the plane to pass through the median landmarks; (d) selection of the left side of the nose – lateral view; (e) selection of the left side of the nose – frontal view, (f) three-dimensional closed structure of the selected side for volume calculation.

2.4. Statistical analysis

Intra- and inter-operator reliability of the volume calculation protocol were verified on 20 randomly selected nasal casts scanned by both system through the Intraclass Correlation Coefficient interpreted according to Koo & Li [53].
The normality and homoscedasticity of the data were tested with the Kolmogorov-Smirnov test and Levene's test, respectively. The significance threshold was set at 0.05 ($\alpha = 0.05$).
The descriptive statistics was reported in terms of mean and standard deviation and the agreement between the volumetric measurements was evaluated through the Lin's Concordance Correlation Coefficient (CCC) [54], interpreted according to McBride [55], and the Passing-Bablok regression [56].
The intra- and inter-operator reliability, the normality and homoscedasticity analysis of the data were performed on SPSS (Version 29.0; IBM Corporation, Armonk, NY), while all the other analyses were completed in R [57].

3. Results

The volume calculation protocol proved to be reliable in terms of both intra-operator repeatability and inter-operator reproducibility. The ICC values with the related 95% Confidence Interval (CI) for the intra- and inter-operator reliability are reported in Table 2.

Table 2. Intraclass correlation coefficients and 95% confidence interval for intra- and inter-operator reliability for volume calculation.

	Intra-observer repeatability	Inter-observer reproducibility
ICC	0.98	0.94
95% CI	0.97 – 0.99	0.91 – 0.96

ICC: Intraclass Correlation Coefficient; CI: Confidence Interval

The data proved to be normally distributed (p = 0.77) and homoscedastic (p = 0.85). All the descriptive statistic values (mean and standard deviation) for right and left nose scanned with the two devices are reported in Table 3.

Table 3. Descriptive statistics

Instrument	Side	Mean ± SD (cm^3)
Stereophotogrammetry	Right	10.41 ± 1.99
	Left	10.85 ± 2.58
	Total	10.63 ± 2.29
Laser Scanner	Right	10.47 ± 1.97
	Left	11.01 ± 2.57
	Total	10.74 ± 2.28
Both instruments	Right	10.44 ± 1.96
	Left	10.93 ± 2.55
	Total	10.69 ± 2.27

SD: Standard Deviation

The agreement between the volumetric values calculated on the nasal casts scanned with two instruments proved positive for both the Lin's Concordance Correlation Coefficient (CCC) and the Passing-Bablok regression. Indeed, the Lin's CCC showed a ρ = 0.99, with the lower one-sided 95% Confidence Interval equal to 0.98, proving "substantial" agreement according to McBride [55]. The Passing-Bablok regression confirmed the interchangeability of the scanning methods in reproducing three-dimensional nasal casts for the calculation of their volume. This statistical methods produced the equation $y = 1.00x - 0.04$ where the 95% CI for the slope $(95\%\ CI: 0.96 - 1.06)$ and the intercept $(95\%\ CI: -0.65 - 0.44)$ included 1 and 0 respectively, confirming that no significant differences between the volumes of 3D nasal model acquired by the two systems exist. The Passing-Bablok regression graph is depicted in Figure 4.

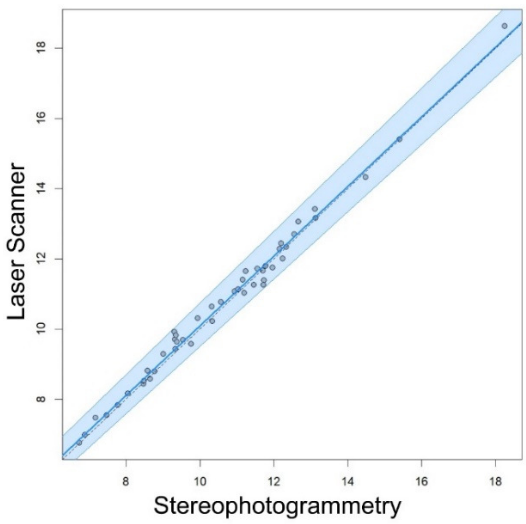

Fig. 4. Passing-Bablok regression line

4. Conclusion

Facial anthropometry is crucial to many scientific fields, such as anatomy, dentistry, surgery, and clinical dysmorphology [11], [23], [24]. The advent of diverse 3D scanning technologies has enabled the acquisition of accurate 3D representations of the face and its structures [33], thereby significantly improving the precision of facial anthropometric analyses: the evaluation of dimensions and proportions mainly performed through linear, angular, and surface measurements. Recently, also volumetric measurements have received greater attention in the craniofacial research and clinical practice. The availability of different 3D scanning technologies and instruments requires studies to verify their interchangeability and reproducibility in performing such analyses.
The present study evaluates the interchangeability of the volumetric measurements of casts of the external nose when scanned with instruments based on two different technologies: stereophotogrammetry (Vectra M3; Canfield Scientific Inc., Parsippany, NJ, USA) and laser scanning (Dental Wings 3Series; Montreal, Canada).
In this study, a novel protocol for the calculation of the volume of the nose has been proposed, and it proved to be repeatable and reproducible in measuring the volume of the left and right nasal side. Evaluating the left and right side of the nose separately can offer advantages in several pathologies, as for instance in unilateral cleft lip and/or palate [58] and other pathologies [59], or in traumas [60], where a unilateral involvement may of the nose may occur. The nasal volumetric measurements calculated on the 3D nasal digital models obtained with the two technologies under examination proved equivalent. This allows the two systems (Vectra M3 and Dental Wings 3Series) to be used interchangeably in scanning the external nose and to compare their data with those reported in the literature from studies that used the same devices examined in this study. However, caution is still needed as different volumetric protocols may give different volumetric values, and different instruments may differently reproduce the same structure providing again different volumetric results. Indeed, some authors [12], [61], [62], [63], [64] calculated the external nasal volume through geometric approximation by means of tetrahedra that, however, do not represent the actual volume of the external nose with an underestimation of the volume. Conversely, Ferrario et al. [51] evaluated the entire external nasal volume on some (n = 20) of the same plaster casts used in this study by reconstructing the three-dimensional models by NURBS. The authors obtained a mean volume for the entire external nose of 19.47 ± 3.11 mm^3, while if we roughly sum the average of the right and left sides of the nose (independently of the used instrument) we would obtain a value of 21.37 cm^3 which is 1000 times bigger. A possible explanation of this difference could reside in the mathematical reconstruction of the nose by the NURBS in the study of Ferrario et al. [51], since such a small volume for adult noses seems non-realistic. In 2015, Codari et al. [44] evaluated the interchangeability of the area measurements on nasal casts scanned with the same instruments evaluated in this study. The authors found that the area measurements on the three-dimensional models obtained with either instrument did not differ significantly. The present study, although using different statistical approaches, extended the work of Codari et al. [44] adding information about the volumetric measurements, confirming the interchangeability of the two systems also for volumetric calculation. Few years later, in 2018, Gibelli et al. attempted to validate two diverse laser scanning systems [40], [65], both different from the one used in the current study: the Sense® (3DSystems, Rick Hill, SC, USA) [65] and the Vi-910 (Konica Minolta, Tokyo, Japan) [40]. The authors conducted a comprehensive investigation of facial anthropometric measurements encompassing linear distances, angles, surfaces, and volumes of the whole face compared with those calculated on 3D models acquired with a system, the Vectra M3, considered as the gold standard. The validation of the Sense® laser scanner [65] was performed on living subjects and on a mannequin head: pertaining to the living subjects, only eight out of 14 linear measurements and eight out of 12 angles provided a "good" agreement according to Camison et al. [66], while all the measurements concerning the mannequin head proved "good" or "very good" agreement. Conversely, the area and volumetric measurements exhibited poor agreement in both cases, indicating that these measurements can not be interchangeably measured in three-dimensional models acquired by the two instruments analysed. Differently, the validation of Vi-910 laser scanner [40] was conducted exclusively on living subjects: the results proved interchangeability for almost all linear measurements and angles as all of the rTEM values found were at least classified as "good". In contrast to the previous study [40], but in accordance with the study by Codari et al. [44], even the surface calculation provided a "good" rTEM value, indicating the feasibility of calculating this parameter on the 3D models obtained with either instrument. Lastly, the volumetric analysis yielded high values of rTEM, indicating that the analysis of volumetric values in 3D models obtained with the Vi-910 or the Vectra M3 provide different results. Concerning the volumetric measurements, which are the focus of the current study, a direct comparison

between our results and those reported by Gibelli et al. [40], [65], is not possible, as they considered a different facial structure (the whole face) and applied a different statistical approach (TEM and rTEM calculation). In addition, the authors did not describe the protocol for the calculation of the facial volume, as the application of different protocols for calculating the volume may influence the final data as recently reported by some authors [67]. In addition, contrasting results on facial anthropometric measurements calculated on 3D models captured with different systems may be attributed to numerous factors, including the accuracy and precision of the scanning instrument, the scanning procedure and time (simultaneous or continuous), and the experimental conditions [65]. Indeed, one has to consider the scanning procedure when dealing with living subjects, as instruments based on a continuous scanning (i.e., the scanner is moved for a prolonged time to cover the entire surface of the object to be acquired, or the object is moved around the scanner) require a longer time of acquisition, producing involuntary motion artefacts (e.g., blinking, breathing). In this perspective, the similar positive results proved in the current study and those reported by Codari et al. [44] may be related to the experimental conditions, as both studies used the same highly accurate and precise 3D scanning instruments to capture and reproduce inanimate objects.
The study here presented is not exempted from limitations that may represent future perspectives in the validation of instruments, particularly for the assessment of volumes that are gaining interest. The first limitation is represented by the sample composed of healthy adult individuals only and of Caucasoid ethnicity. Although there should be no differences in the volume calculation of the external nose due to factors potentially influencing its shape and size (e.g., age, ethnicity, health status), it would be beneficial to verify this assumption through a comprehensive analysis encompassing the entire lifespan and including non-healthy and non-Caucasoid individuals. A second limitation is represented by the "*in vitro*" nature of the study, and the interchangeability of the scanning methods and the applicability of the protocol should be evaluated in 3D images of living subjects. Additionally, the protocol should also be tested for the analysis of other structures to verify whether it could be a reference protocol applicable for several structures, and it should also be tested against other protocol of data recording and analysis to verify their agreement. Lastly, although the two instruments proved to be interchangeable for the 3D volumetric assessments of the external nose, it should be evaluated whether the extant differences between the volumetric values, although minimal, are clinically significant or not, which was not possible in this study as a clinical threshold value is still not present in literature.

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