Original Article

Comparative Analysis between Linear Measures from Bidimensional and Three-dimensional Images of the Face for Human Identification Purpose: A Pilot Study

Abstract

Introduction: Photo-anthropometry is a method of facial image comparison that consists of taking measurements on images. The objective of this study was to verify if facial measurements obtained from a two-dimensional (2D) image can be applied for the purpose of human identification when compared with measurements obtained from a three-dimensional (3D) image. **Materials and Methods:** In this cross-sectional research, a convenience sample was formed by 3D and 2D images of 12 participants. In these images, 35 linear measurements were taken between landmarks. The 2D images were obtained in different angles and norms (left and right sides, and front sides), and the measures were categorized into vertical, lateral, and lip regions. The data were organized in Excel® spreadsheets (Microsoft Corp., Redmond, Washington, USA) and submitted to descriptive statistics. **Results:** The vertical measurements in lateral norms were more divergent than the measurements of 3D images, whereas the measurements of the lip region showed less differences in all norms. In the lateral norms, vertical measures such as nasion–pogonion were underestimated by 14.35 mm, whereas this same measure was overestimated by 7.20 mm in the frontal norm. In the lip region, the most underestimated measures were crista philtri (left)–cheilion (left) at 5.95 mm and crista philtri (right)–cheilion (right) at 5.45 mm, and the most overestimated was cheilion (right)–cheilion (left) at 4.38 mm, all in the frontal norm. **Conclusion:** The facial measurements obtained in 2D images can be underestimated or overestimated depending on the angle and norm of each image.

Keywords: *Face, forensic anthropology, forensic dentistry, forensic sciences, photogrammetry*

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Introduction

In forensic sciences, photographs or images obtained from surveillance cameras have been used as evidence of materiality in questioned situations.[1] In criminal contexts, when the identification of a person suspected of having committed theft or murder is necessary, facial images obtained from surveillance cameras can be compared with images of suspected people in an attempt to arrive at a probable identity.[2-4]

This process of facial analysis by images for forensic purposes can be performed by morphologic comparison, overlap, or photo-anthropometry of anatomical structures.[5] In the process of facial image comparison, two-dimensional (2D) images are used due to their availability since they may be the only material available for analysis.[2,6,7] However, to be properly analyzed, factors linked to the quality of the images, such as the suspect's movement and ambient lighting, must be considered.[8-10] In addition, the presence of photographic distortions from the camera configuration and its position in relation to the suspect is an important variable that must be considered.[11-13]

On the contrary, although facial analysis does not include a method of human identification,[14] images of the face have already been used for this purpose,[9] and their use has also been evaluated using techniques for obtaining three-dimensional (3D) images, such as digital stereophotogrammetry.[15,16]

Digital stereophotogrammetry is a technique that uses 2D images obtained in a controlled

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manner to build a 3D image of the face with realistic dimensions and proportions.[17-20] On the contrary, 2D images were also associated to estimate the dimensions of the face in a 3D image for the purpose of human identification.[21]

Thus, the development of new technologies and image resources has enabled research on human identification through images,[2,15,16] but it has also enabled the study of known methodologies, such as photo-anthropometry, which recommends taking measurements on facial anatomical structures represented in 2D images to differentiate one person from another.[5] Thus, the objective of this study was to verify whether facial measurements obtained from a 2D image can be applied for the purpose of human identification when compared with facial measurements obtained from a reference 3D image.

Materials and Methods

Ethical approval for this study (Ethical Committee N° 86380818.8.0000.5440) was provided by the Ethical Committee of General Hospital of the Medical School of Ribeirão Preto of the University of São Paulo, Ribeirão Preto, on 07 October 2019. For the conduct of this cross-sectional study, a convenience sample composed of 12 participants of both sexes (six men and six women) was selected. The participants were aged between 17 and 19 years, were healthy, and expressed consent to carry out this research. The sample did not include volunteers who had a medical or dental history of (I) trauma or facial surgery; (II) syndromic conditions or severe pathologies; and (III) facial hair or scars.

The 3D images were obtained by a single calibrated examiner, who followed the protocol adopted by the LRESS laboratory of the University SDRP-USP. This protocol includes the steps concerning the preparation and positioning of the participant, as well as the way to view and identify the facial landmarks before and after obtaining the 3D images, as following explained. Thus, the participants had their hair tied with a strip of fabric, they were sitting in front of a digital stereophotogrammetry model VECTRA M3® (Canfield Scientific Inc., Fairfield, New Jersey, USA) [Figure 1], and the face without expression of all the participants was positioned according to reference lines that the device determines.

Before obtaining the 3D images, 39 facial landmarks [Table 1] were identified through visual inspection and with the aid of a black eyeliner (quem disse, berenice?®, Interbelle Comércio de Produtos de Beleza Ltda., São Paulo/SP, Brazil). After obtaining the images, the landmarks were removed with a make-up remover (quem disse, berenice?®, Interbelle Comércio de Produtos de Beleza Ltda.) and gauze pads from the Cremer® brand (Dental Cremer Produtos Odontológicas, Blumenau/SC, Brazil).

Landmarks [Table 1] were again identified in the 3D images using the VECTRA® 3D Analysis Module software (Canfield Scientific Inc., Fairfield, New Jersey, USA), which was also used to perform 35 linear measurements [Table 2] and that were considered to be the gold standard of analysis.[23,24] However, although the protocol adopted by LRESS laboratory recommends the identification of landmarks on the full face, in this research, only some points belonging to the middle and lower facial thirds were used, as observed in Table 2.

Figure 1: Digital stereophotogrammetry device used to obtain the 2D and 3D images (VECTRA M3®, Canfield Scientific Inc., Fairfield, New Jersey, USA)

Then, the same linear measurements were performed on the six 2D images obtained at six different angles by the digital stereophotogrammetry apparatus and which were used in the formation of the 3D image of each participant [Figure 2]. For this, the Fiji image processing package (https://fiji.sc/) was used.

As shown in Figure 2, a 3D image is formed by the rendering of six 2D images obtained in different angles; in these images, the numbers (1–3) comprise the lateral (left and right) and frontal norms, and the letters (A and B) comprise different angles (10° between each pair of images).

Thus, once the value of the different angles was not considered in this pilot study, the analyses were performed from the average value obtained between each pair of images (angles A and B) for each participant, and compared with the gold standard. In addition, as summarized in Table 2, the measurements performed were categorized into vertical, lateral (left and right), and lip region to reduce distortion in the images caused by the different angles [Figure 2].

Thus, the data obtained were organized in Excel® spreadsheets (Microsoft Corp., Redmond, Washington,

Table 1: Landmarks identified in the 3D images

Landmarks (abbreviation) – localization		
Trichion (Tr) – midline at the capillary intersection	Glabella (G) – most prominent point between the eyebrows	Nasion (N) – deeper point between the forehead and the nose
Pronasale (Prn) – most anterior point of the tip of the nose	Columella (C) – most prominent point at the base of the nose	Subnasale (Sn) – lowest point at the intersection of the base of the nose
Labiale superius (Ls) – midpoint at the beginning of the vermilion of the upper lip	Stomion (Sto) – intersection of the facial midline and the horizontal cleft lip	Labiale inferius (Li) – midpoint at the beginning of the lower lip vermilion
Sublabiale (Sl) – point in the midline of the lip groove	Menton (Me) – most anterior point of mentonian symphysis	Gnathion (Gn) – most inferior and anterior point of the mentonian symphysis
Pogonion (Pg) – most anterior point of the chin	Cheilion (Ch[*r] Ch [†l]) – lip commissure	Exocanthion (Ex[*r] Ex[†l]) – external eye fissure commissure
Endocanthion (En[*r] En[†l]) – internal eye fissure commissure	Frontotemporale (Ft[*r] Ft[†l]) – laterally to the elevation of the temporal line	Orbitale (Or[*r] Or[†l]) – in the infraorbital groove
Orbitale superius (Os[*r] Os[†l]) – in the supraorbital groove	Cheek (Chk[*r] Chk[†l]) – intersection between the Camper plane and the line between the Ex and Ch points	Zygion (Zy[*r] Zy[†l]) – lateral point of the zygomatic arch
Alare (Al[*r] Al[†l]) – most lateral point of the contour of the nostrils	Crista philtri (Cph[*r] Cph[†l]) – on each raised edge of the nasal filter	Crista alare (Ac[*r] Ac[†l]) – in the outer part of the wing of the nose
Tragion (T[r] T[†l]) – on the upper edge of the Tragus	Gonion (Go[r] Go[†l]) – most lateral point of the mandible angle	

Adapted from Ferrario *et al*.[22] *Right. †Left.

Table 2: Categorization and specification of all linear measurements performed

Linear measurements			
Right lateral	**Vertical**	**Left lateral**	**Lip region**
Go[*r]–T[*r]	N–Pg	Go[†l]–T[†l]	Sn–Sto
Gn–Go[*r]	N–Gn	Gn–Go[†l]	Ls–Sto
Go[*r]–Pg	N–Sto	Go[†l]–Pg	Sn–Ls
Chk[*r]–T[*r]	N–Me	Chk[†l]–T[†l]	Sto–Li
Ch[*r]–T[*r]	Sn–Pg	Ch[†l]–T[†l]	Cph[*r]–Cph[†l]
Ch[*r]–Go[*r]	Sn–Gn	Ch[†l]–Go[†l]	Li–Me
	Sn–Me		Ls–Cph[*r]
			Ls–Cph[†l]
			Cph[†l]–Ch[†l]
			Cph[*r]–Ch[*r]
			Li–Ch[†l]
			Li–Ch[*r]
			Ls–Li
			Ch[†l]–Chk[†l]
			Ch[*r]–Chk[*r]
			Ch[*r]–Ch[†l]

Ch, cheilion; Chk, cheek; Cph, crista philtri; Gn, gnathion; Go, gonion; Li, labiale inferius; Ls, labiale superius; Me, menton; N, nasion; Pg, pogonion; Sn, subnasale; Sto, stomion; T, tragion. *Right. †Left.

USA) and submitted to descriptive statistics based on the analysis of the mean of each measure. Thus, in this study, measures that differed by more than 2 mm were considered to have clinical/forensic relevance.[23,24]

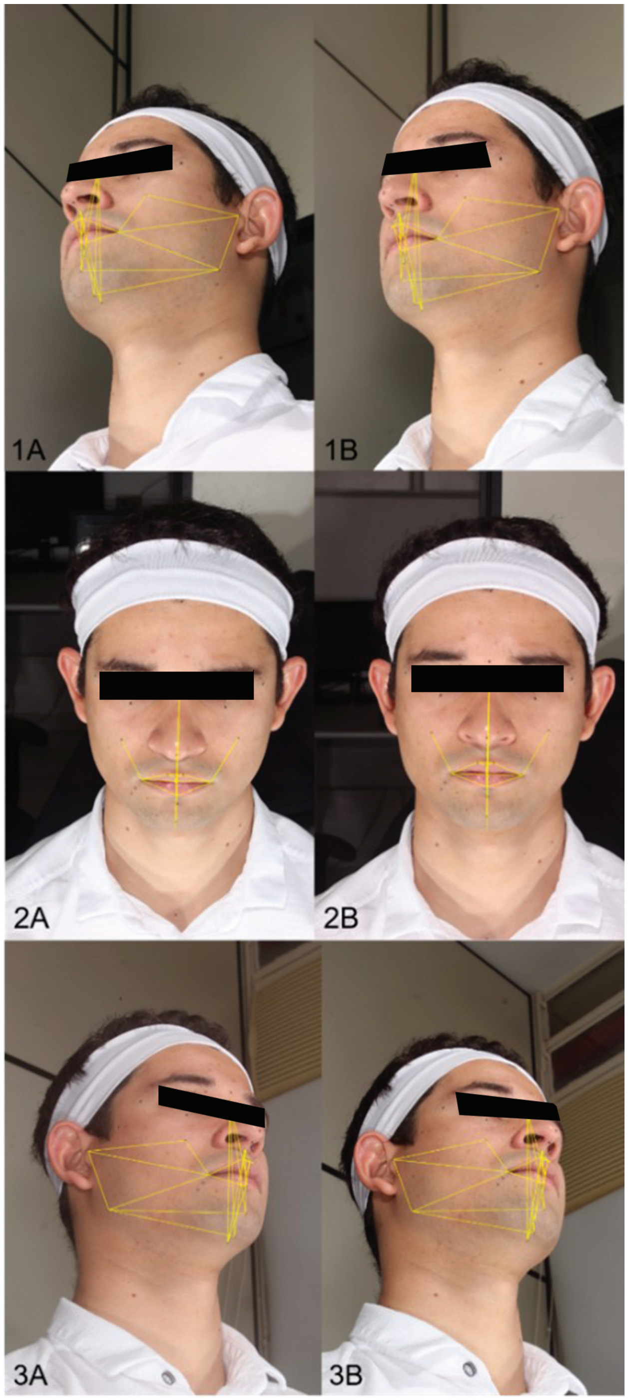

Figure 2: Two-dimensional images obtained simultaneously by the digital stereophotogrammetry device, named according to the device's specification. The numbers comprise the lateral norms (1–left and 3–right) and 2–frontal, whereas the letters correspond to the different angles

Results

With the analysis of the data, it can be observed that the vertical measures nasion–pogonion, nasion–gnathion, nasion–stomion, nasion–menton, subnasale–pogonion, and subnasale–gnathion had their values underestimated in the 2D images when considering the mean of the angles A and B in the lateral norms (right and left), whereas the subnasale–menton measure had its value overestimated by an average of 1.67 mm (lateral norm left) and 1.06 (lateral norm right) [Figure 3].

On the contrary, the nasion–pogonion, nasion–gnathion, and nasion–stomion measurements had their values overestimated in 2D images when considering the mean of angles A and B in the frontal norm. In this norm, the nasion–menton, subnasale–pogonion, subnasale–gnathion, and subnasale–menton measurements were not considered due to the nonvisualization of the landmarks resulting from the photographic distortion.

In Figure 4, a similar behavior can be observed between the measurement values in both lateral norms (left and right). Thus, it was found that some measurements were underestimated, whereas others were overestimated in relation to 3D measurements. The measures on the left side gonion–tragion, cheek–tragion, and cheilion–tragion were underestimated by, respectively, 7.16, 8.06, and 10.97 mm, whereas on the right side, these same measures were underestimated by 6.08, 8.65, and 10.13 mm, respectively [Figure 4]. In addition, the gnathion–gonion, gonion–pogonion, and cheilion–gonion measures on the left side were overestimated by, respectively, 3.02, 4.16, and 1.96 mm, whereas these same measures on the right side were overestimated in 2.82, 3.49, and 1.56 mm, respectively [Figure 4].

Still in relation to the lateral measurements, when the left and right regions are compared, one can also verify a similar behavior between them. Thus, the measurements on the right side were, in general, less divergent from the 3D measurements than the measurements on the left side [Figure 4].

With regard to the measures categorized as belonging to the region of the lips, it can be observed that, in general, they presented smaller mean differences between the means of the 2D and 3D measures in relation to the lateral (left and right) and vertical measures [Figures 5 and 6]. In this case, the most underestimated measures were crista philtri (left)–cheilion (left) at 5.95 mm and crista philtri (right)–cheilion (right) at 5.45 mm, and the most overestimated was cheilion (right)–cheilion (left) at 4.38 mm, all in the frontal norm [Figure 5].

A global view of the average differences between measurement categories can be made in Figure 6. Thus, as can be observed, there was a tendency to underestimate the value of vertical and lateral measurements, whereas there was a tendency to overestimate the measurements of the lip region [Figure 6].

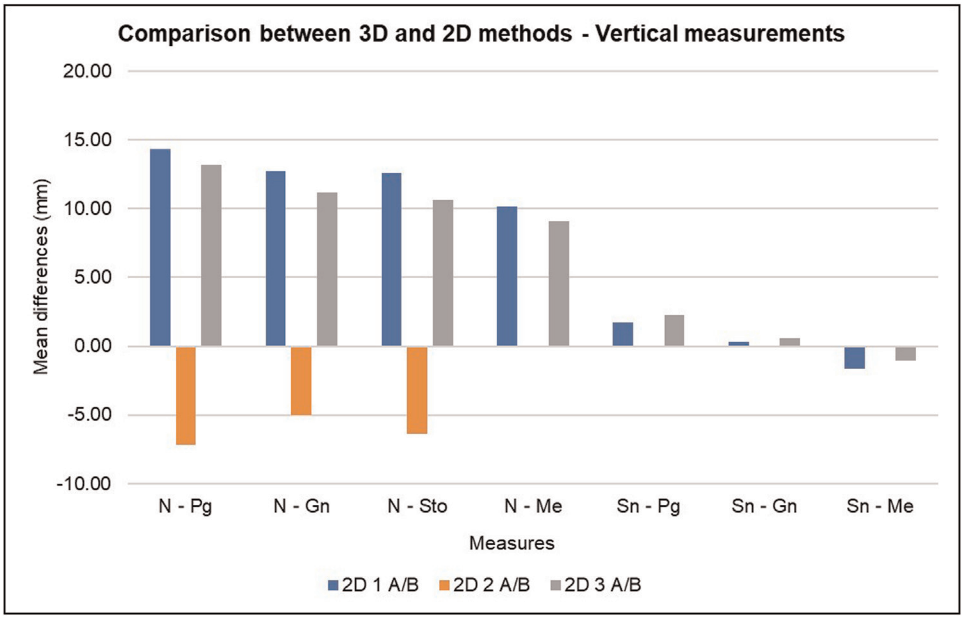

Figure 3: Mean differences between the averages of vertical measures. The abscissa axis represents the value of 3D measurements. N, nasion; Sn, subnasale; Sto, stomion; Pg, pogonion; Gn, gnathion; Me, menton. The numbers 1, 2, and 3 represent the left, front, and right side standards, respectively. The letters A/B represent the average of the different angles

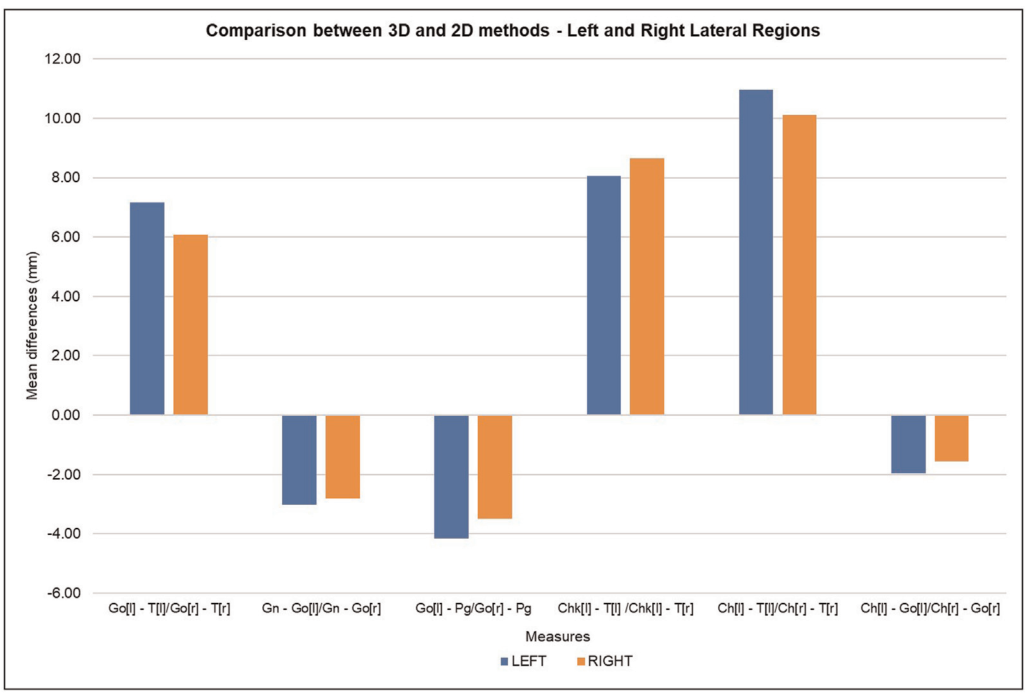

Figure 4: Comparison of the mean differences between the means of the left and right lateral measurements. The abscissa axis represents the value of 3D measurements. N, nasion; Sn, subnasale; Ls, labiale superius; Sto, stomion; Li, labiale inferius; Pg, pogonion; Gn, gnathion; Me, menton; Ch, cheilion; Chk, cheek; Cph, crista philtri; T, tragion; Go, gonion; r, right; l, left

Discussion

The identification of living people by means of images has been highly requested, and comprises a theme that has been studied with the use of 2D and 3D images of the face.[2,25] However, the quality of images and photographic distortions include limitations in the analysis of images.[10,11] Due to factors like these, photo-anthropometry has not been recommended as a method of human identification.[5] Thus, the present research verified the differences between linear measurements from 2D and 3D images. For this purpose, the present research included landmarks that are less susceptible to the influence of facial expressions, but that would possibly be visible in images from surveillance cameras.[13]

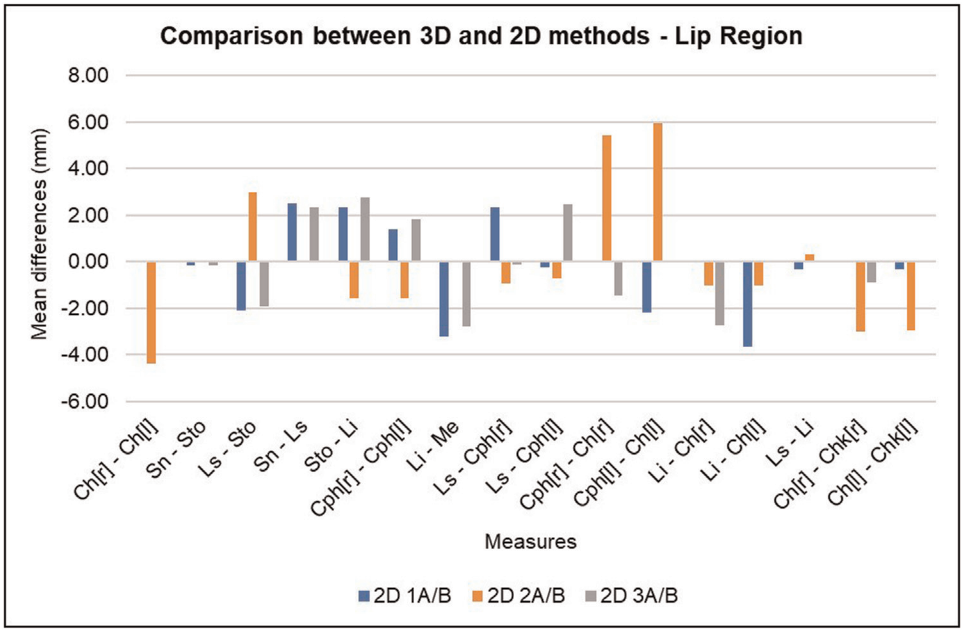

Figure 5: Mean differences between the mean measurements of the lips region. The abscissa axis represents the value of 3D measurements. Sn, subnasale; Ls, labiale superius; Sto, stomion; Li, labiale inferius; Me, menton; Ch, cheilion; Chk, cheek; Cph, crista philtri; r, right; l, left. The numbers 1, 2, and 3 represent the left, front, and right side standards, respectively. The letters A/B represent the average of the different angles

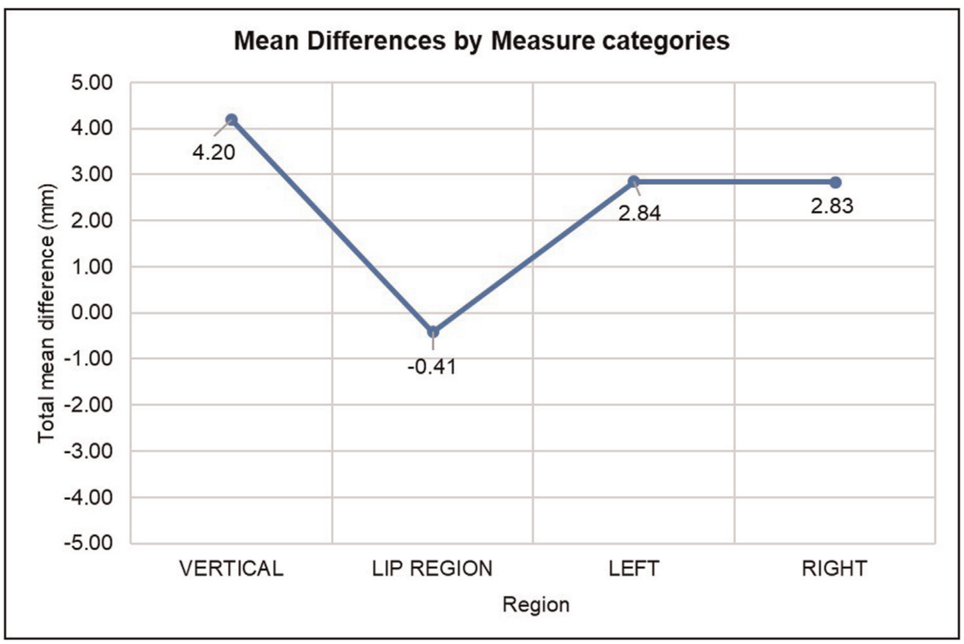

Figure 6: Global view of the average differences between each category of measures. The abscissa axis represents the value of 3D measurements

Ideally, the compared faces should be immobile, and represented from the same perspective (angle and direction).[11,13] In this research, several limitations of photo-anthropometry were overcome. High quality and standardized images were obtained, as 2D images were captured simultaneously by the digital stereophotogrammetry device. In addition, the digital stereophotogrammetry device was immobile [Figure 1], in an environment with controlled lighting, and captured the images in the order of milliseconds, which reduced the bias related to the participant's movement.[11,13] Finally, the images did not suffer loss of details due to export and compression, as they were analyzed in raw format.[12]

Thus, it was observed that among the different categories used, certain vertical measures obtained from the lateral norms showed more divergent values in relation to the measures obtained from 3D images. For example, on the left side images, there was an average underestimation of

14.35 mm in the nasion–pogonion measure. Despite this, in this same context, the subnasale–gnathion measure showed an average underestimation of only 0.30 mm, whereas the subnasale–menton measure averaged overestimation only 1.67 mm [Figure 3].

As in the research by Moreton and Morley,[10] the landmarks carried out in this research changed to a lesser or greater degree depending on the norm (lateral or frontal) and angulation of the image in which it was performed. In their research, Moreton and Morley[10] used proportionality indices (PIs) obtained from linear measurements, and found that variations in facial proportions in the same individual can occur under different perspectives. The vertical PIs tested by Moreton and Morley[10] changed significantly by changing the camera's position by 10° in the vertical direction.

With regard to the changes that PIs can undergo, Kleinberg and Vanezis[11] used 2D images from five participants with a 10% difference between them and demonstrated that this change causes considerable changes in PIs resulting from the combination of linear point measurements of horizontal anthropometric measurements with ectocanthion–Stomion or nasion–stomion linear measurements. On the contrary, in the research by Kleinberg and Vanezis,[11] a smaller variation in PIs was observed with anthropometric points oriented vertically and diagonally.

In the research by Kleinberg *et al.*,[12] a difference of 10° in relation to the frontal norm consisted of a limitation, although in real situations, the compared images are not under the same perspective. Because of these changes and possibilities, the present research considered the average of the measurements between each pair of images, which had a difference of 10° between them. However, the combination of linear measures to obtain indices represents a limitation of photo-anthropometry when the indices do not consider a measure that undergoes less variation, as highlighted by Machado *et al.*[7] in his research on age estimation.

In the present study, the vertical measurements obtained from the frontal norm were overestimated to a lesser extent. For example, the nasion–pogonion measure was overestimated by an average of 7.20 mm [Figure 3], which suggests that there is a tendency for vertical measurements to be a little more faithful to the 3D reference image if obtained from the frontal norm [Figure 3]. However, in the lip region, the measurements obtained in the frontal norm presented values close to those obtained in the lateral norms, although overestimated or underestimated, depending on the laterality of the image, as was the case of the measurement labiale superius–labiale inferius, that in the frontal and right lateral norms, it was underestimated in average by 0.32 and 0.07 mm, respectively, whereas in the left lateral norm, it was overestimated in average by 0.32 mm, probably due to the presence of photographic distortions [Figure 5].

Therefore, it is possible that the analyses in photo-anthropometry should be oriented according to the standard and the probable angulation of the image, so that in this way, it is possible to decide on which measures can be used in the comparison. However, the set of measures used in this research mixed linear measurements obtained from landmarks that are more distant or closer, which according to Kleinberg and Siebert[13] can consists of a limitation, as smaller linear measures are more sensitive to accuracy in location of anthropometric points, where small errors in location can generate major changes in PIs.

Thus, the results of this research encourage further research in photo-anthropometry both for the purpose of human identification and other challenging forensic themes, such as age estimation, which is fundamental in combating crimes against child sexual exploitation.[7,26] In the context of age estimation, Machado *et al.*[7,26] found an interesting correlation between measurements of the lower facial third and facial growth. Thus, promising results were found in the photoanthropometric analysis to age estimation.[26,27]

However, there may be proximity to the values of the measures and indices obtained between different people.[12,21] Thus, Martos *et al.*[21] used computer graphic techniques to estimate the dimensions and PIs in a 3D image from 2D images, and found that the overlap between measurement intervals between different people can lead to false-positive or false-negative identification results. Therefore, morphologic differences (physical appearance) between two individuals may not be translated into differences by photoanthropometric analyses.[12]

In view of these possibilities, the present research did not propose an approach to human identification, but evaluated the effect that photographic distortions can have on linear facial measurements, as they are used to obtain or even as an alternative to PIs.[13] Although the use of reasons or PIs can compensate for the effect of photographic distortions,[13] understanding the effect of photographic distortions on each linear measure can guide the choice of more reliable PIs.

On the contrary, factors related to facial asymmetry and accuracy in locating landmarks should also be considered.[6,21,28-31] In this sense, as landmarks are identified prior to obtaining the images, the digital stereophotogrammetry technique allows more accurate measurements to be taken.[23] In addition, although asymmetry is present to a greater or lesser degree on the human face,[29,30] very close values between the left and right lateral measurements were found [Figure 4], which suggests that further research in human identification through images may be performed using either hemiface. Furthermore, the possibility of using either side of the face for photoanthropometric analysis is especially useful when there are traumas, minor pathologies, or abnormalities on one side of the face such as hemifacial atrophy or neural palsy. On the contrary, even if only one hemiface is available for comparison, the presence of such morphologic characteristics can, in themselves, be individualizing.

Thus, research and analysis that focus on the use of a hemiface for human identification as an alternative to not viewing contralateral landmarks due to photographic distortion or face rotation[11] are encouraged, as well as research that proposes analyses on the full face, which can be achieved if a 3D × 3D facial comparison is employed.[15] In addition, 3D images obtained by the digital stereophotogrammetry technique can be rotated and enlarged, in addition to allowing linear measurements of area, volume, and angle in different regions of the face, which have additional advantages over 2D images.[18,20,32] However, digital stereophotogrammetry devices are more expensive than conventional digital cameras, and need an adequate environment to be ideally used.[19,20,32]

However, despite the promising results obtained in this pilot study, the main limitation of this research was the small sample size. Therefore, research that overcomes this limitation can be useful in clarifying the role of photo-anthropometry in human identification, that means, whether the method can be improved or not.

Conclusion

It is concluded that facial measurements obtained in 2D images can be underestimated or overestimated to a greater or lesser extent according to the angle and norm of each image when compared with facial measurements obtained from a 3D image. Thus, it is likely that to be used for the purpose of human identification, each measurement obtained from a 2D image must be analyzed individually and used with caution according to the angle and norm of each image.

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Conflicts of interest

There are no conflicts of interest.

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