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A comparison between 2D and 3D methods of quantifying facial morphology

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ABSTRACT

Objectives: Currently, two & three-dimensional (2D & 3D) imaging techniques have largely replaced the direct anthropometric method in the assessment of facial morphology, but the difference between the two techniques was not quantified. Therefore, the aim of this study was to compare and quantify (the difference between) the two techniques.
Materials and methods: The faces of 150 subjects (75 males, 75 females) of northern Nigeria, predominantly Hausa ethnic group, were photographed (using digital camera) and scanned (using a 3D surface laser scanner). Facial dimensions were generated from the resulting virtual 2D and 3D models. Data were analyzed using R-statistic software & Paired sample t-test/Pearson correlation were conducted to compare the two methods and to quantify the level of closeness between the two measurements.
Results: Intraclass correlation coefficient (ICC) was very low (0.26) for the 3D and 2D measurements indicating the level of differences between the methods. Measurements taken with laser scanner were higher relative to the one taken by camera. The mean differences between the 3D and the 2D methods of quantifying facial morphology indicated a statistically significant positive difference. CONCLUSION: 2D and 3D anthropometry cannot be used interchangeably since there exists statistically significant variation between the two methods.

1. Introduction

Currently, 2D and 3D imaging techniques are mainly used for the assessment of the human facial morphology and largely replaced direct anthropometry, which in the past, was the only method for the assessment of the human facial morphology, and was the only source of large volume of literature on human face anthropometry (Farkas, 1994; Aung et al., 1995; Zankl et al., 2002). Studies intended on large population is barely impossible with direct anthropometry, simply because it is time consuming, and again not suitable for infants and children. The major disadvantage with the direct anthropometry is its inability to provide digital coordinate record of the participants for later use in order to extract new facial measurements. The use of the metallic instruments (e.g., Vernier, Sliding or Spreading Calipers) may occasionally press against the measured soft tissues, and the accuracy and reliability of this technique is therefore skeptical. The use of the two dimensional (2D) (Langlois and Roggman, 1990; Ferrario et al., 1993; Rhodes, 1998; Rhodes et al., 2005; Rennels et al., 2008; Lee et al., 2010; Hooder and Souza, 2012), and three dimensional (3D) measurement techniques (Burke, 1971; Burke and Healy, 1993; Ras et al., 1995; Heike et al., 2010; Verhoeven et al., 2013; Ladeira et al., 2013), in the quantification of facial morphology has largely replaced the direct anthropometric method in the recent time. However, the preference and accuracy of one over the other is largely equivocal, which culminated into comparative studies (Farkas, 2002; Weinberg et al., 2006; Ghoddousi et al., 2007; Noyan et al., 2011; Joe et al., 2012; Kramer et al., 2012). The 2D method poses many advantages, for example, rapid acquisition of images, archival capabilities and low cost. Although more expensive than the 2D, 3D method has simplified the craniofacial studies and thus the availability of 3D cone beam computed tomography (CBCT) (Cevidanes et al., 2009; Nada et al., 2011), 3D surface laser scanning (Toma et al., 2008; Djordjevic et al., 2011), 3D stereophotogrammetry (Maal et al., 2010; kau et al., 2011) and other 3D methods allow for description and comparison of 3D facial images, quantification of facial morphology (Ghoddousi et al., 2007;

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Jayaratne and Zwahlen, 2014). In the real sense, the development of optical scanning technology has enhanced facial morphology research from 2D to three-dimension (3D) (Aung et al., 2000; Toma et al., 2009; Berssenbrugge et al., 2014; Vezzetti et al., 2018).

Recently, 3D ultrasonography was interestingly used to extract reference points of fetal faces automatically (Moos et al., 2017) and the authors claim high level of accuracy. Although this method is interesting, but it is only limited to fetuses, albeit it may possibly be good for internal organs such as Heart, Liver, Kidneys and the rest and therefore, physical anthropometry is virtually impossible with such method.

Similarly, automatic method for the extraction of facial morphological features was recently devised from the 3D facial scans with 97% face classification accuracy (Abbas et al., 2015), thereby simplifying the whole process. Comparison between 2 methods can be used to determine the performance evaluation of technical equipment (Enciso et al., 2004; Aung et al., 1995, Aung et al., 2000).

Although the 2D and 3D methods of quantifying facial morphology are the most commonly used techniques, studies are yet to quantify the levels of variation between the two methods. Therefore, the aim of this study was to determine the levels of differences between 2D and 3D methods of quantifying facial dimensions. This paper was organized with the following headings: Introduction, materials and methods, results, discussion and conclusion.

2. Materials and method

2.1. 3D images capturing (scanning) technique and processing

The study recruited 150 participants from Kano and Kaduna States in Nigeria, predominantly Hausa ethnic group, by simple random sampling. The participants were recruited only after receiving informed consent and was also informed that their privacy rights of human subjects will be observed and the that the study was purely anonymous. The age range was 18–25 years. The faces of the study participants were scanned using Exascan 3D Laser surface scanner from Creaform® (www.handyscan3d.com), and saved in a computer for analyses. Prior to the commencement of the study, the scanner was calibrated to correct any optical or electronic distortions and the sensor configured for dark skin. Prior to scanning, positioning targets were placed on the face of each participant, from the hair line down to the chin, and along each side of the face including the ears. Test scans were conducted with the participant lying supine with and without the use of a dough-nut shaped head rest and with the subject sitting down still. The preliminary results indicated better images with the participants sitting rather than lying supine. Scanning was done with each participant seated in an upright position, asked to sit still on a chair with the head facing up (neck extended) at a slight angle of about 45° relative to the floor, as this position was found to be the most comfortable to scan eliminating the need for the researcher to bend over while aquiring images. Participants were instructed to keep their eyes closed to avoid discomfort from the laser beams. During the scanning process, the 3D digital scan is generated on the computer screen in real time, allowing the researcher to continue scanning until a satisfactory scan has been created (Fig. 1). Good quality 3D facial scans were obtained with the subject maintaining a natural pose with neutral facial expression (see (Peter et al., 2004). In a situation where the position or pose of the subject distorted the face, or if the facial expression was not neutral, the scans were discarded as the inclusion of non-neutral facial expressions would have affected morphological comparisons between subjects (see (Peter et al., 2004). Each of the obtained scan was then trimmed and cleaned of any mesh (e.g., Fig. 2) before the analyses.

2.2. 3D linear measurements using landmarks

Facial dimensions were acquired by using standard landmarks (Table 1) on various locations of the face (Figs. 3 and 4) using the

Fig. 1. Un-cleaned scanned face.

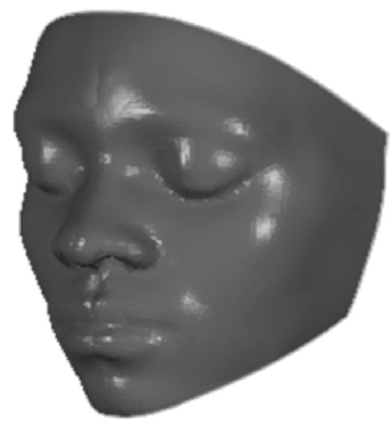

Fig. 2. Cleaned scanned face.

Geomagic studio software 12. Raw landmark coordinates were exported into Excel and saved as *.csv file* (comma delimited) for each individual. The metrics of each facial scan for each individual were acquired from a personally designed template using the coordinates of a single scan. Facial geometrical features are extracted from the Cartesian coordinates of the neoclassical canonical landmarks as reference points (Vezzetti and Marcolin, 2012). The Euclidean distances (dimensions) are most often extracted by the use of the Pythagoras formula which corresponds to the Euclidean distance, and the Euclidean distance between points X and Y is the length of line connecting the 2 points [See (Moos et al., 2017; Vezzetti et al., 2018; Cirrincione et al., 2018)].

Pythagoras formula: SQRT $((X1\text{-}X2)^2+(Y1\text{–}Y2)^2+(Z1\text{-}Z2)^2)$.

Each individual measurement so acquired from the template, was saved as *.xls file*, were copied and pasted into the main Excel file in ascending order of the questionnaire number. Normality of the facial metrics data was tested using the ‘Kolmogorov Smirnov’ and ‘Shapiro tests’ to guide the type of analysis (Schoder et al., 2006; Ghasemi and Zahediasl, 2012).

2.3. 2D linear measurements using landmarks

The facial dimensions were recorded to the nearest millimetres (mm) from the 2D facial images, performed using Facial art software with magnification factor of 0.5 (Fig. 5). The software automatically calculated all the measurements identified on each landmark record, which were then transferred to Microsoft excel.

Table 1
Summary of facial landmarks used in this study and their descriptions.

Point	Landmark	Name	Description
P1	ex (r)	Exocanthion	Outer commissure of the right eye fissure
P2	so (r)	Supraorbitale	The most prominent point on the right supraorbitale
P3	en (r)	Endocanthion	Endocanthion of the right eye fissure
P4	N	Nasion	Midpoint between the eyes, just above the bridge of the nose
P5	en (l)	Endocanthion	Endocanthion of the left eye fissure
P6	so (l)	Supraorbitale	The most prominent point on the left supraorbitale
P7	ex (l)	Exocanthion	Exocanthion of the left eye fissure
P8	zy (r)	Zygion	The most lateral point on the right cheek
P9	al (r)	Alar	Most lateral point on the right alar contour
P10	Sn	Subnasale	Mid-point of angle at columella base
P11	al (l)	Alar	Most lateral point on the left alar contour
P12	zy (l)	Zygion	The most lateral point on the left cheek
P13	go (r)	Gonion	The point at the angle of the (r) mandible
P14	ch (r)	Chelion	Point located at right labial commissure
P15	Ls	L. superior	Midpoint of the border of the upper lip
P16	ch (l)	Chelion	Point located at left labial commissure
P17	go (l)	Gonion	The point at the angle of the left mandible
P18	Sto	Stomium	Midpoint of closed lip
P19	Li	L. inferior	Midpoint of the lower vermilion
P20	gn	Gnathion	The lower-most point on the mid-anterior of the menton
P21	pr	Pronasale	The most prominent point on the tip of the nose
P22	sl	Sublabius	Midpoint of the junction between the lower lip and the chin

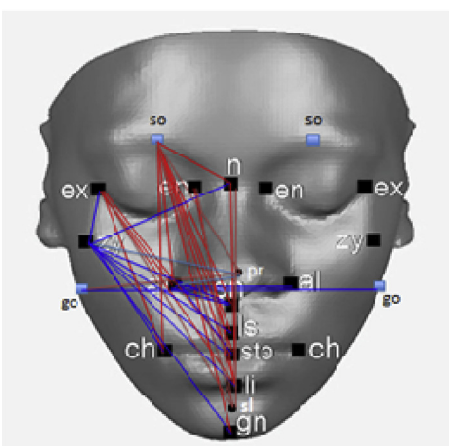

Fig. 3. Sexually dimorphic dimensions. Red dimensions greater in females & Blue dimensions greater in males.

2.4. 2D images capturing (photo-taking) technique and processing

The face of each of the 150 study subjects was captured using 24-mm wide-angle lens camera (Sony, model DSC-W380 made in china), with a shutter speed of 1/125 per second, and a primary flash light. A 100-mm focal lens and a zooming power of 3.6 was selected in order to maintain the natural proportions. Each of the participant was positioned on a line marked on the floor, which is about 100cm (kept constant) from another marked lined just in front of the former line, similar to the method used by Joe et al., (2012). Each of the participants was asked to stand erect facing the camera, and was also asked to maintain a neutral face adopting the position they normally show during the day, and an identification number was placed behind the participant so as to merge each subject with his/her 3D scans. The operator ensured that the participant's forehead, neck, and ears were clearly visible during the recording.

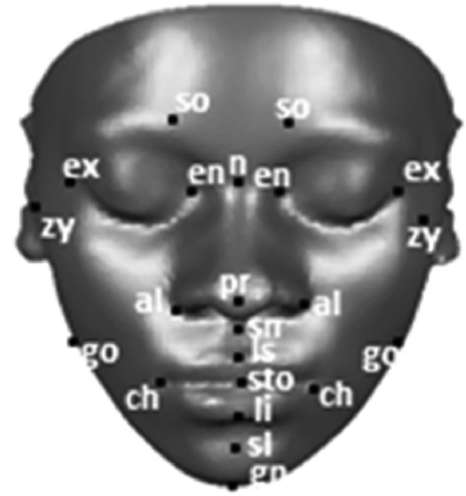

Fig. 4. 22 landmarks used for quantifying facial shape.

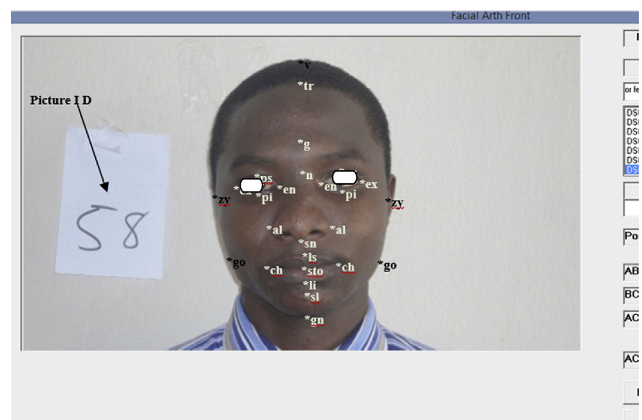

Fig. 5. 2D Facial landmarks and Art face software interface.

2.5. Ethical approval

This study has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and was approved by the National Health Research Ethics Committee (NHREC) of Nigeria.

3. Results

3.1. Repeatability (Intra-observer error)

Intra-observer analysis was carried out using the method adopted by Osvaldo et al. (2012), by re-measuring the same metrics on the 25 randomly selected scans 2 weeks after the first 25 sets of measurements and the data were then analyzed using Paired Samples T-Tests. Measurement error was below 5% for all metrics and substantially lower for most, but some metrics differed in their mean values between first and second measurements. Intraclass correlation coefficient (ICC) was very low (0.26) for the 3D and 2D measurements (Table 2) indicating the level of differences between the methods of quantifying facial morphology. Table 3 shows the comparison between the means of the 2D and 3D facial dimensions using paired t-test. In all the twelve (12) pairs compared, measurements taken with laser scanner were higher relative to the one taken by camera. The mean differences between the 3D and the 2D methods of quantifying facial morphology indicated a positive difference which were found to be statistically significant in all the pairs considered (Table 4).

Table 2
Intraclass correlation coefficient.

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	P - value
Single Measures	0.01	0.01	0.02	16.67	148	3700	0.0001
Average Measures	0.26	0.15	0.38	16.67	148	3700	0.0001

Table 3
Comparison of 2D and 3D facial dimensions.

Parameters		Mean ± SD	Correlation	P - value
Pair 1	Exen3D	42.30 ± 2.95	0.33	0.0001
	exen2D	25.51 ± 3.02		
Pair 2	exzy3D	42.08 ± 5.83	0.31	0.0001
	exzy2D	15.14 ± 1.81		
Pair 3	exal3D	55.01 ± 3.44	0.31	0.0001
	exal2D	37.61 ± 5.11		
Pair 4	exch3D	74.28 ± 4.41	0.43	0.0001
	exch2D	57.07 ± 6.63		
Pair 5	enzy3D	77.32 ± 5.84	0.30	0.0001
	enzy2D	36.25 ± 4.06		
Pair 6	enal3D	38.45 ± 2.77	0.37	0.0001
	enal2D	28.02 ± 3.76		
Pair 7	ench3D	71.21 ± 4.07	0.45	0.0001
	ench2D	51.83 ± 6.39		
Pair 8	zyal3D	83.77 ± 6.92	0.71	0.037
	zyal2D	37.94 ± 5.55		
Pair 9	zych3D	87.77 ± 7.24	0.33	0.0001
	zych2D	51.88 ± 6.18		
Pair 10	alal3D	40.80 ± 4.11	0.57	0.0001
	alal2D	34.16 ± 4.72		
Pair 11	zyzy3D	139.55 ± 6.50	0.31	0.0001
	zyzy2D	98.93 ± 11.15		
Pair 12	nsn3D	48.11 ± 3.32	0.31	0.0001
	nsn2D	40.38 ± 5.10		
Pair 13	enen3D	30.59 ± 3.45	0.36	0.0001
	enen2D	28.65 ± 4.09		

Table 4
Mean differences between 3D and 2D.

Parameters		Paired Differences			t- value	P - value
		Mean ± SD	95% CI of the Difference			
			Lower	Upper		
Pair 1	Exen3D- exen2D	16.79 ± 3.45	16.23	17.35	59.31	0.0001
Pair 2	exzy3D - exzy2D	26.94 ± 5.55	26.04	27.84	59.20	0.0001
Pair 3	Exal3D- exal2D	17.39 ± 5.22	16.55	18.24	40.67	0.0001
Pair 4	Exch3D- exch2D	17.21 ± 6.19	16.21	18.22	33.96	0.0001
Pair 5	Enzy3D- enzy2D	41.07 ± 6.02	40.09	42.05	83.22	0.0001
Pair 6	Enal3D- enal2D	10.42 ± 3.75	9.81	11.03	33.90	0.0001
Pair 7	Ench3D - ench2D	19.38 ± 5.84	18.43	20.32	40.49	0.0001
Pair 8	Zyal3D- zyal2D	45.83 ± 8.10	44.52	47.14	69.08	0.0001
Pair 9	Zych3D- zych2D	35.88 ± 7.79	34.62	37.15	56.20	0.0001
Pair 10	Alal3D- alal2D	6.65 ± 4.14	5.98	7.32	19.58	0.0001
Pair 11	Zyzy3D- zyzy2D	40.62 ± 11.04	38.83	42.40	44.91	0.0001
Pair 12	Nsn3D - nsn2D	7.73 ± 5.14	6.89	8.56	18.37	0.0001
Pair 13	Enen3D- enen2D	1.94 ± 4.29	1.24	2.63	5.50	0.0001

4. Discussion

Direct anthropometric measurements have been used for the study of facial morphology for long period of time. In the recent time, 2D photographs are commonly used for such studies and for assessment and treatment of facial abnormalities. However, the 2D images in assessing facial morphology is subject to errors because the natural 3D facial anatomy will be translated in 2D (Enciso et al., 2004). The latest 3D imaging devices are specifically designed to capture and quantify facial morphology and are presently very common in the research environments (Da Silveira et al., 2003; Fourie, 2010; Plooij et al., 2011; Knoops et al., 2017). These 3D devices were purposely manufactured just to address the shortcomings of the 2D imaging systems, and several of them are now available to generate 3D surface facial images such as laser scans, stereo-photogrammetry, and infrared imaging (Enciso et al., 2004; Weinberg et al., 2006; Tzou et al., 2014). The three-dimensional (3D) surface imaging with its advances, are having a dramatic impact on the field of craniofacial anthropometry (Bailey and Byrnes, 1990). Relatively few studies have directly compared anthropometric measurements obtained through alternative methods. Previous studies have focused mainly on the concordance between direct and indirect measurement techniques, comparing traditional caliper-based anthropometry with either standard 2D photogrammetry (Guyot et al., 2003) or cephalometry (Guyot et al., 2003; Budai et al., 2003). Along these same lines, a few studies have also compared direct anthropometric measurements with those obtained by way of indirect 3D surface imaging methods, including traditional stereo-photogrammetry (Weinberg et al., 2006; Meintjes et al., 2002), surface laser scanning (Baca et al., 1994; Aung et al., 1995), and fully automated digital 3D photogrammetry (Losken et al., 2005; Weinberg et al., 2006).

Our study has, to some extent, quantified the levels of the differences between 2D and 3D measurement of facial morphology. The findings of our study were in agreement with the results obtained by van Vlijmen et al. (Van VLIJMEN et al., 2009), where they compared 2D images obtained from radiographs and cone beam computed tomography (CBCT)-constructed 3D models. They reported a statistically significant difference between the 2D and 3D measurements.

Although, these methods serve as veritable tools in the study of facial morphology for varying purposes, they cannot be used interchangeably, more especially in clinical evaluation of facial form diagnosis as pointed out by Zamani (2015). In the developing world where there is no 3D scanners, direct and 2D anthropometry are the only means of assessing and evaluating facial morphology, however, it has to be noted that the advantages of those two methods should not be overemphasized over the 3D since in the 2D anthropometry, the depth of the face is lost. The fact that there is a statistically significant difference between two-dimensional and three-dimensional images, the 2D facial models can still be used especially when assessing or evaluation of facial dimensions with less significant differences as seen in the previous table.

5. Conclusion

The 2D method of quantifying facial morphology is one of the easiest and cheap method in the field of facial anthropology (a field in the Biological anthropology), simply because it is non-invasive, less time consuming, not boring to the participating subjects and above all, data from this method is easy to analyze. However, despite its advantages, the 3D method is far better, especially in terms of accuracy and additional depth of the image been taken, but 2D is still a useful tool in Bio-anthropology despite its limitations and disadvantages.

Declarations

Author contribution statement

Anas I. Y., BAMGBOSE B. O., SALEH NUHU: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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