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Stereophotogrammetry-based Facial Depth Measurements: A Novel Method for Quantifying Facial Projection

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Abstract

Background—Orthognathic surgery leads to alteration of the spatial relationship of the mandible and maxilla resulting changes in the degree of facial projection. Traditional 2-D cephalometry and photographic techniques do not provide data on facial depth. Though stereophotogrammetry can be used as a non-invasive method for evaluating facial depth, the unavailability of ethnicity-specific norms hinder its routine use in clinical practice. The objectives of this study were to 1. Generate an analytic scheme suitable for evaluating facial depth using stereophotogrammetry, and 2. Create normative data for the facial depth measurements for young Hong Kong Chinese adults.

Methods—Stereophotographic images from 41 male and 45 female ethnic Chinese young adults without facial deformities were analyzed. Facial depth measurements were performed based on standard anthropometric landmarks, with the aid of 3dMDVultus software.

Results—All facial depth measurements were found in absolute terms to be significantly higher in males. In contrast, the upper face, maxillary and sublabial depth indices were significantly higher in females, whereas no significant gender differences emerged for lower facial and maxillomandibular indices.

Conclusions—A novel method of using stereophotographic images for quantifying facial depth was evaluated. Normative facial depth measurements for young Hong Kong Chinese adults were established. This gender-specific database can be used as a reference in the diagnosis, treatment planning, or evaluation of outcomes after surgical correction of facial deformities.

Introduction

The face is distinctive in terms of its prominent location and anatomical complexity.¹ Even though restricted to a relatively confined space this region plays a vital role in interpersonal communication, mastication, deglutition and respiration. It conveys information about a person's age, gender, race, emotions, general well-being, and even personality traits.^{1–2} Aesthetic, functional and psychosocial factors need to be taken into account when performing surgical and non-surgical interventions in the maxillofacial region.

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Orthognathic surgery leads to alteration of the spatial relationship of the mandible and maxilla resulting changes in the degree of facial projection. The literature is replete with studies using lateral cephalometry and photography for the characterization of facial morphology.³⁻⁴ While these techniques permit assessment of the profile and frontal views, they do not reveal information about the facial depth. In addition, humans are used to view themselves in the mirror as a 3-D object, which gives an indication of the facial depth. When discussing treatment options with patients, it is quite difficult to convey information on changes in the facial projection with traditional 2-D imaging.

Karel Hajnis⁵ was the first to record point to point facial depth measurements based on traditional manual anthropometric techniques. These measurements were recorded directly from living subjects using calipers. The left tragus was used as the reference from which linear distances were measured to the nasion, subnasale and gnathion. With the evolution of anthropometric techniques several other facial depths were added to the battery of measurements. However, the conventional manual anthropometry is a time-consuming technique and requires direct contact with the subject. This may be difficult to measure in small children or other individuals who are unwilling to cooperate with operators of a different gender due to cultural or religious reasons.

With the advent of stereophotography now it's possible to acquire a resolute 3-D image of the face.⁶ The stereophotographic systems use several pairs of identical cameras for acquiring 3-D surface data with natural colour and texture. Some commercial systems are capable of 180-degree facial capture or more in less than two milliseconds.⁷ Digital anthropometric measurements can be performed on these 3-D images using specialized software.⁸

Stereophotogrammetry can be used as a non-invasive technique for performing facial depth measurements. Several proportions describing the projective characteristics of the face can be calculated based on such measurements. Nevertheless, unavailability of race specific norms for facial depth measurements prevents the routine use of such techniques when evaluating dismorphic faces or their changes following surgical or non-surgical interventions such as orthodontic treatment. At the moment facial depth data for young Hong Kong Chinese adults are unavailable in the literature. Therefore, the objectives of this study were 1. to generate an analysis scheme suitable for evaluating facial depth using stereophotogrammetry and 2. to create normative facial depth measurements for young adults of Chinese ethnicity in Hong Kong.

Materials and Methods

Subjects

Stereophotographic images obtained from 41 males and 45 females meeting the following criteria were used for this study.

- Ethnic Chinese
- Between 18 to 35 years of age
- Balanced faces with clinical Class I dento-skeletal pattern

- Both tragus visible in 3-D images

Excluded were all individuals with gross facial deformities, facial asymmetries, severe bimaxillary protrusions, incompetent lip closure and those with a history of previous facial trauma, orthognathic and/or plastic surgery, and orthodontic treatment. This study was approved by the Institutional Review Board of The University of Hong Kong/Hospital Authority Hong Kong West Cluster (Protocol No: UW 12-066).

The minimum sample size for each gender was calculated according to the procedures outlined by the International Organization for Standardization (ISO) on “General Requirements for Establishing Anthropometric Databases”.⁹ This ISO standard uses the following formula for calculating the sample size.

$$N = \left(\frac{1.96 \times CV}{a} \right)^2 \times 1.534^2$$

1.96 - Critical value (z value) for a 95 % confidence interval

CV - Coefficient of variation (=SD/Mean × 100%)

a - Percentage of relative accuracy desired

The CV for the right maxillary depth (sn-t) from Farkas *et al.*¹⁰ was used as the parameter of interest with desired level of accuracy set at 2%. Thus the minimum sample size required according the above equation for males and females would be 28 and 35 respectively.

Image Acquisition

The 3-D facial photographs were acquired with the *3dMDface* stereophotography system (3dMD, Atlanta, USA). This system has been validated in terms of its accuracy and reliability.¹¹⁻¹² The subjects were seated in a chair placed at a set distance from the cameras while looking at a mirror placed in front of them. Participants were required to wear a surgical cap in order to cover their hair, but both ears were left exposed.

Measurement Technique

A set of anthropometric landmarks for this study were selected based on Farkas¹³⁻¹⁴ and Kolar.¹⁵ The landmarks tragon, gnathion and chelion were redefined to suit stereophotogrammetry according to Wong *et al.*¹⁶ (Table 1).

Landmark identification and all measurements were performed by a single investigator (YSNJ) who has been trained and calibrated by an expert in craniofacial anthropometry (CKD). The acquired images were loaded to *3dMDVultus* software (3dMD, Atlanta, USA). Following the identification of landmarks (Fig. 1) the analysis template was activated facilitating automatic calculation of linear measurements. These measurements were then saved as Excel[®] spread sheets (Microsoft Inc, Florida, USA) for further statistical analysis using SPSS (see below).

Error Analysis

Randomly selected sample of 11 images were re-measured under the same conditions at least three weeks after the initial measurement session. The technical error of measurement (TEM) was calculated using Dahlberg's formula.¹⁷

$$\text{TEM} = \sqrt{\frac{\sum d^2}{2n}}$$

d = difference between measurements

n = number of measurements

Statistical Analysis

The linear measurements between landmarks were averaged and standard deviations were calculated. The two-sample Student's t-test was applied to determine any significant differences between males and females for each measurement. The paired t-test was used to compare bilateral measurements from the left and right face. These statistical tests were performed using IBM SPSS statistics version 20 (IBM, New York, USA).

Results

No significant differences were found in relation to the average age of male (23.59 ± 2.59 years) and female (23.36 ± 3.50 years) subjects. The TEM ranged between 0.80mm and 1.29 mm for the majority of measurements, except for right and left lower face depths (t-gn), which were 1.75mm and 1.54mm, respectively.

All facial depth measurements were significantly larger in males (Table 2). In relation to bilateral measurements for each facial depth, the difference between right and left counterparts were not statistically significant except supraorbital (t-g) and upper facial depth (t-n) in both genders. The upper facial, maxillary and sublabial depth indices were significantly higher in females whereas no significant gender differences were found for lower face and maxillomandibular depth indices (Table 3).

Discussion

The depth measurements operationally define the degree of facial projection. To the authors' knowledge this is the first study to document facial depths using stereophotogrammetry. Though these norms were derived for Hong Kong Chinese, this data set could provide reference values in other parts of Southern China as the inhabitants share a common 'Han' ancestry.¹⁸ Furthermore, these norms could be of value for clinicians in countries outside of China that have many Southern Chinese descendants.

The data generated from this study may be useful when planning orthognathic surgery and evaluating post-surgical changes in adults with facial deformities. Ideally, surgery should aim to create a facial appearance matching the population mean of the corresponding age, gender and ethnicity. Further, knowledge of these key facial depth measurements could be

of value when deciding the type and extent of surgery. Normal measurements could be used as indicators of the appropriate amount of change needed to correct facial disproportions. In addition, facial depth measurements and proportions proposed in this study could be used to compare pre- and post-operative 3-D images. The surgical outcome can be quantified to determine if a marked reduction in the degree of abnormality has been achieved.¹¹

We also calculated some of the facial indices reported by Farkas and Munro.¹⁴ However, it was necessary to modify some of the traditional nomenclature in order to facilitate articulation. For example the traditional ‘skull base width-middle third face depth index’ was substituted with the term maxillary depth index ($t-t/sn-t \times 100$). The sublabial depth, sublabial depth index and maxillomandibular index which were not part of the traditional manual anthropometric analysis scheme were introduced in order to specifically address dentofacial deformities. Proportional depth indices such as upper face ($t-t/n-t \times 100$), maxillary ($t-t/sn-t \times 100$), sublabial ($t-t/sl-t \times 100$), and lower face ($t-t/gn-t \times 100$) depict the degree of facial projection. For example, if the upper facial depth ($t-n$) were reduced, the $t-n-t$ distance would also decrease and, as a result, its ratio to the bitragal width (i.e., the upper face depth index) would increase. Thus an increase in these indices indicates a flat or “dish” face.

The maxillomandibular index proposed here could be useful in the assessment of the morphologic relationship between the maxilla and mandible. The midline soft tissue landmarks subnasale and sublabiale used in this index are within in close proximity to their cephalometric hard tissue counterparts A and B point. As the triangle $t-sn-t$ and $t-sl-t$ encompassed by these landmarks gives an indication about the relative size of the maxilla and mandible respectively. Thus a higher maxillomandibular index ($t-snt/t-sl-t$) would indicate mandibular retrognathism, while a lower index could be expected in mandibular prognathism or maxillary hypoplasia.

The landmark tragon is sometimes obscured in 3D images. Therefore, identifying the tragon, which is a base landmark for facial depths, becomes problematic. Such images were excluded from this study as masking prevents the accurate calculation of facial depth measurements.

As the next stage of this project we plan to evaluate these facial depth measurements and indices in different deformity types.

Conclusion

A novel method of using stereophotographic images for quantifying facial depth is described here. Normative facial depth measurements for young adults of Chinese ethnicity in Hong Kong were established. All facial depth measurements were significantly higher in male participants. The upper face, maxillary, and sublabial depth indices were significantly higher in females, while no significant gender differences were found for lower face and maxillomandibular depth indices. The gender-specific normative data presented in this study can be used as references for diagnosis, pre-operative treatment planning, or evaluation of post-operative treatment outcomes following the correction of facial dysmorphism.

References

1. Cole, J. About face. London: The MIT Press; 1999.
2. Giddon DB. Orthodontic applications of psychological and perceptual studies of facial esthetics. *Semin Orthod.* 1995; 1:82–93. [PubMed: 8935047]
3. Jayaratne YS, Zwahlen RA, Lo J, Cheung LK. Facial soft tissue response to anterior segmental osteotomies: a systematic review. *Int J Oral Maxillofac Surg.* 2010; 39:1050–1058. [PubMed: 20705431]
4. Vasudavan S, Jayaratne YS, Padwa BL. Nasolabial soft tissue changes after Le Fort I advancement. *J Oral Maxillofac Surg.* 2012; 70:e270–e277. [PubMed: 22285331]
5. Hajniš K. Kopf-, ohrmuschel- und handwachstum (Verwendung bei den operationen der angeborenen missbildungen und unfallfolgen). *Acta Univ Carol (Biol).* 1974; 2–4:77–294.
6. Kau CH, Richmond S, Incrapera A, English J, Xia JJ. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. *Int J Med Robot.* 2007; 3:97–110. [PubMed: 17619242]
7. Jayaratne YS, Zwahlen RA, Lo J, Tam SC, Cheung LK. Computer-aided maxillofacial surgery: an update. *Surg Innov.* 2010; 17:217–225. [PubMed: 20513723]
8. Jayaratne YS, Lo J, Zwahlen RA, Cheung LK. Three-dimensional photogrammetry for surgical planning of tissue expansion in hemifacial microsomia. *Head Neck.* 2010; 32:1728–1735. [PubMed: 19862829]
9. Organisation, IS. ISO 15535: General Requirements for Establishing Anthropometric Databases. Geneva, Switzerland: 2006.
10. Farkas, LG.; Ngim, RCK.; Lee, ST. Craniofacial norms in 6–12-and 18-year-old Chinese subjects. In: Farkas, LG., editor. *Anthropometry of the head and face.* New York: Raven Press; 1994. p. 337–346.
11. Weinberg SM, Naidoo S, Govier DP, Martin RA, Kane AA, Marazita ML. Anthropometric precision and accuracy of digital three-dimensional photogrammetry: comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry. *J Craniofac Surg.* 2006; 17:477–483. [PubMed: 16770184]
12. Aldridge K, Boyadjiev SA, Capone GT, DeLeon VB, Richtsmeier JT. Precision and Error of Three-Dimensional Phenotypic Measures Acquired From 3dMD Photogrammetric Images. *Am J Med Genet A.* 2005; 138:247–253. [PubMed: 16158436]
13. Farkas, LG. *Anthropometry of the Head and Face.* 2nd ed.. New York: Raven Press; 1994.
14. Farkas L, Munro I. *Anthropometric facial proportions in medicine:* Charles C. Thomas Publisher. 1987
15. Kolar JC, Salter EM. *Craniofacial anthropometry: Practical measurement of the head and face for clinical, surgical, and research use:* CC Thomas. 1997
16. Wong JY, Oh AK, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. *Cleft Palate Craniofac J.* 2008; 45:232–239. [PubMed: 18452351]
17. Harris EF, Smith RN. Accounting for measurement error: A critical but often overlooked process. *Arch Oral Biol.* 2009; 54
18. Wen B, Li H, Lu D, et al. Genetic evidence supports demic diffusion of Han culture. *Nature.* 2004; 431:302–305. [PubMed: 15372031]
19. Swennen, GRJ.; Schutyser, F.; Hausamen, JE. *Three-dimensional cephalometry: a color atlas and manual.* Springer Verlag; 2005.

Figure 1.

Anthropometric landmarks and facial depth measurements used for this study (ch – cheilion, ex – exocanthion, g – glabella, gn – gnathion, n – nasion, sn – subnasale, sl – sublabiale, t – tragon, A - supraorbital depth, B - upper facial third depth, C - orbito-tragial depth, D - maxillary depth, E - labio-tragial depth, F - sublabial depth, G - lower face depth)

Table 1

Definition of anthropometric landmarks used in this study

Name	Abbreviation	Definition
Glabella	g	The most prominent midline point between the eyebrows ¹³
Nasion	n	The midpoint on the soft tissue contour of the base of the nasal root ¹⁹
Subnasale	sn	The midpoint of the angle at the columella base where lower border of the nasal septum and the surface of the upper lip meet ¹³
Exocanthion	ex	The soft tissue point located at the outer commissure of each eye fissure ¹³
Sublabiale	sl	The midpoint of the Labiamental sulcus ¹⁵
Cheilion	ch	The most lateral aspect of the vermilion border of the corner of the mouth ¹⁶
Gnathion	gn	The point on the inferior border of the mandible at which it intersects the midline ¹⁶
Tragion	t	The most superior aspect of the tragus where it abuts the face ¹⁶

Table 2

Normative facial depth measurements for Hong Kong Chinese

Measurement	Mean (mm)	SD	95% Confidence Interval for Mean		Statistical significance	
			Lower Bound	Upper Bound		
Bitragal Width (t-t)	Male	154.51	5.35	152.82	156.19	<0.001
	Female	144.74	5.33	143.13	146.34	
Right supraorbital depth (t-g)	Male	130.40	4.28	129.05	131.76	<0.001
	Female	121.13	4.28	119.84	122.41	
Left supraorbital depth (t-g)	Male	129.24	4.75	127.74	130.74	<0.001
	Female	120.05	4.28	118.77	121.34	
Right upper facial third depth (t-n)	Male	122.44	4.02	121.17	123.71	<0.001
	Female	113.01	3.70	111.89	114.12	
Left upper facial third depth (t-n)	Male	120.87	4.25	119.53	122.21	<0.001
	Female	111.75	3.96	110.56	112.94	
Right orbito-tragial depth (t-ex)	Male	83.56	3.70	82.39	84.72	<0.001
	Female	78.38	3.66	77.28	79.48	
Left orbito-tragial depth (t-ex)	Male	84.07	4.58	82.63	85.52	<0.001
	Female	78.59	4.10	77.36	79.82	
Right labio-tragial depth (t-ch)	Male	116.19	6.00	114.30	118.09	<0.001
	Female	106.45	4.21	105.19	107.72	
Left labio-tragial depth (t-ch)	Male	115.99	5.14	114.37	117.62	<0.001
	Female	106.40	4.29	105.11	107.69	
Right maxillary depth (t-sn)	Male	130.62	4.38	129.24	132.00	<0.001
	Female	119.52	4.12	118.29	120.76	
Left maxillary depth (t-sn)	Male	129.98	4.48	128.56	131.39	<0.001
	Female	119.14	4.10	117.91	120.37	
Left sublabial depth (t-sl)	Male	141.53	4.98	139.96	143.10	<0.001
	Female	129.71	4.60	128.32	131.09	
Right sublabial depth (t-sl)	Male	141.98	7.17	139.72	144.25	<0.001

Measurement	Mean (mm)	SD	95% Confidence Interval for Mean		Statistical significance
			Lower Bound	Upper Bound	
Right lower face depth (t-gn)	Female	129.61	4.75	128.19	131.04
	Male	146.79	5.48	145.06	148.52
	Female	135.68	5.63	133.99	137.37
Left lower face depth (t-gn)	Male	147.08	5.61	145.31	148.85
	Female	136.02	5.45	134.38	137.66

Table 3

Normative proportional indices for Hong Kong Chinese

Index	Mean	SD	95% Confidence Interval for Mean		Statistical significance	
			Lower Bound	Upper Bound		
Upper face depth index ($t-t/t-n-t \times 100$)	Male	63.52	1.58	63.02	64.01	0.021
	Female	64.41	1.92	63.84	64.99	
Maxillary depth index ($t-t/t-sn-t \times 100$)	Male	59.31	1.75	58.76	59.87	0.001
	Female	60.66	1.72	60.14	61.18	
Sublabial depth index ($t-t/t-sl-t \times 100$)	Male	54.57	2.49	53.78	55.35	0.008
	Female	55.84	1.82	55.29	56.38	
Lower face depth index ($t-t/t-gn-t \times 100$)	Male	52.61	1.92	52.01	53.22	0.096
	Female	53.31	1.90	52.74	53.88	
Maxillomandibular index ($t-sn-t/tsl-t \times 100$)	Male	91.97	2.41	91.21	92.73	0.085
	Female	92.06	1.91	91.49	92.63	