Application of Digital Anthropometry for Craniofacial Assessment

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Craniomaxillofac Trauma Reconstruction 2014;7:101–107

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Abstract

Craniofacial anthropometry is an objective technique based on a series of measurements and proportions, which facilitate the characterization of phenotypic variation and quantification of dysmorphology. With the introduction of stereophotography, it is possible to acquire a lifelike three-dimensional (3D) image of the face with natural color and texture. Most of the traditional anthropometric landmarks can be identified on these 3D photographs using specialized software. Therefore, it has become possible to compute new digital measurements, which were not feasible with traditional instruments. The term "digital anthropometry" has been used by researchers based on such systems to separate their methods from conventional manual measurements. Anthropometry has been traditionally used as a research tool. With the advent of digital anthropometry, this technique can be employed in several disciplines as a noninvasive tool for quantifying facial morphology. The aim of this review is to provide a broad overview of digital anthropometry and discuss its clinical applications.

Keywords

- anthropometry
- face
- 3D imaging
- reference values

Facial morphology is an important phenotypic feature that aids in the diagnosis of several craniomaxillofacial and genetic disorders. Surgeons have been working for several decades on the refinement of techniques available for reconstruction in patients with maxillofacial deformities. However, the complex three-dimensional (3D) structure of this region along with esthetic and functional considerations pose significant challenges to their quest. Osteotomies to correct dysgnathic jaws and various facial asymmetries as well as craniofacial corrections and reconstructive surgery after trauma and tumors lead to changes in overlying soft tissues and consequently of the facial appearance. Thus, clinicians require baseline data on the external and internal soft tissue morphology both of the normal and deformed faces. In addition, the changes that occur in the face following treatment need to be objectively evaluated and collected in databases.

Clinicians may be able to assess craniofacial deformities by visual examination alone.[1] These assessments, termed "anthroposcopy" are highly subjective and some of the deformities may not be obvious to the naked eye. Furthermore, anthroposcopy neither provides quantitative data nor identifies specific anatomic parameters responsible for the deformities. Therefore, a systematic method for analyzing facial phenotypic data are warranted.

Anthropometry is an alternative method that could be used to assess the human morphology. Compared with the latter, this assessment delivers quantitative measurements.[2] The field of anthropometry can be divided into two main streams.

1. Craniofacial anthropometry: Measurements performed on the head and face.
2. Somatometry: Measurements performed on the rest of the body.[2]

Craniofacial anthropometry is an objective technique based on a series of measurements and proportions, which facilitate the characterization of phenotypic variation and quantification of dysmorphology. In contrast to anthroposcopy which tends to be unreliable,[3] anthropometry can be very reliable when performed by a trained practitioner.[4] The

received
May 16, 2013
accepted after revision
July 7, 2013
published online
March 17, 2014

DOI http://dx.doi.org/10.1055/s-0034-1371540.
ISSN 1943-3875.

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Historical Overview

The technique of anthropometry was first developed by the German anatomist, Johann Sigismund Elsholtz in 1654.[5] Prior to this, the term "anthropometry" generally had been used during philosophical discussions about the human soul. Throughout the last century, anthropometry has witnessed as an extensive development. Elsholtz's technique was widely used in the 18th century and early 19th century for human growth studies and classification of populations based on quantitative morphology. Much of the early research focused on the cephalic index, which is the ratio between cranial width and length. The development of instruments such as spreading and sliding calipers allowed more comprehensive body measurements. By 1870, an independent German school of thought on anthropometry was emerging, culminating with the 1882 Frankfurt convention.[2] A long-term outcome of this meeting was the consensus on standardizing head posture for measurements, which is referred to as the "Frankfurt horizontal plane."

In 1920, Aleš Hrdlička wrote a monograph called anthropometry,[6] setting the North American standards in this field. He proposed the use of this technique in medicine with a battery of 14 measurements. The number of measurements gradually rose with the subsequent application of this technique for studying craniofacial anomalies.

Leslie Farkas can be considered to be the pioneer of modern craniofacial anthropometry having published 241 scientific works including four seminal books about anthropometry.[7–9] Being dissatisfied with the limitations of visual examination, Farkas began exploring the application of classical anthropometric techniques for quantitative evaluation of faces before and after surgery. His collaboration with anthropologist Karel Hajnis paved the way to develop a facial measurement scheme for patients with congenital anomalies

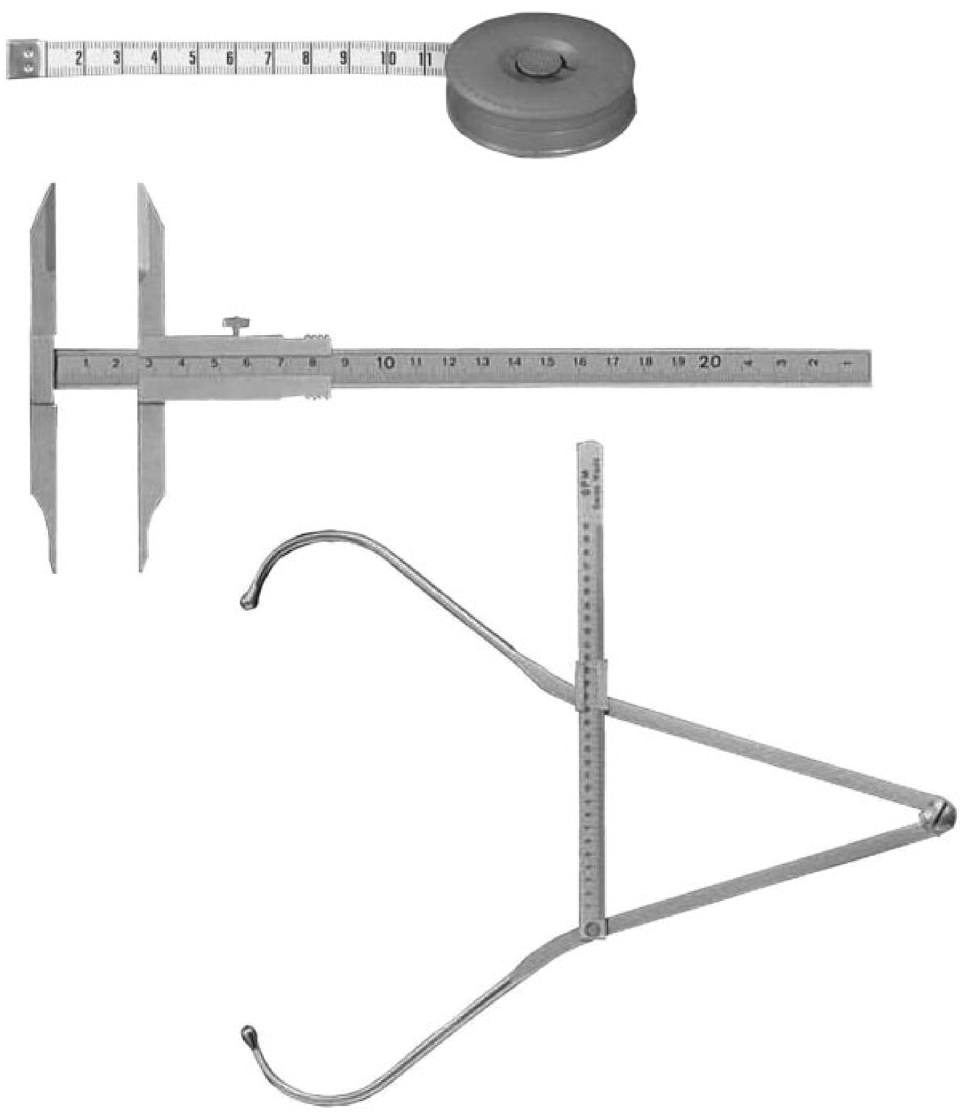

Figure 1 Some of the instruments used for manual anthropometry.

and traumatic facial deformities.[7] As normative anthropometric reference data were unavailable, Farkas took the lead in creating a large database of norms for North American White adults and children. After realizing the limitations of using only linear measurements, several proportional indices for assessing the facial framework were added.[10]

Manual Anthropometry

Generally, anthropometric measurements are taken directly from the subject using calipers and measuring tape (►**Fig. 1**). Proportions were calculated using these measurements. The conventional manual anthropometry is a time consuming technique, which requires direct contact with the subject, sometimes with sharp instruments. This can be inappropriate for small children or subjects who may not prefer direct contact due to personal or cultural reasons. The need to repeatedly locate landmarks for each measurement can introduce errors and prolong the measuring time. In addition, compliance is problematic, as patients have to remain motionless while the measurements are taken. As this technique does not leave an archival record on the facial appearance other than a set of numbers, some errors become permanent.[11] The accuracy of the measurements will inevitably depend on the skill and experience of the operator. The chances for errors are likely to be considerable, especially when anthropometry is performed by nonexperts.[11]

Manual anthropometry has been mainly used for research purposes in evaluating deformities such as cleft lip and palate deformity or craniosynostoses.[12–16] Because of the limitations mentioned above, this technique has not been popular as a routine clinical tool.

Anthropometric Landmarks

A total of 47 craniofacial anthropometric landmarks has been described.[17] The definitions of some important landmarks in the maxillofacial region are listed in ►**Table 1**. Many of these landmarks can be identified visually, while palpation is required to locate few landmarks related to underlying skeletal structures.[18]

Digital Anthropometry

With the introduction of stereophotography it is possible to acquire a lifelike 3D image of the face with natural color and texture. These stereophotographic systems consist of several pairs of identical cameras positioned at specific angulations for acquiring 3D surface data. Some commercial systems are capable of 180 degree facial capture in less than 2 milliseconds.[19] Most of the traditional anthropometric landmarks can be identified on these 3D photographs using specialized software (►**Fig. 2**). Some of the conventional anthropometric landmarks such as zygion, gonion, maxillofrontale, or orbitale require palpation for their accurate identification. It is not feasible to incorporate measurements associated with these landmarks to the 3D analysis scheme. Therefore with appropriate modifications, conventional anthropometric techniques can be applied for quantification of 3D photos. In addition, it is also possible to compute new digital measurements, not being feasible to perform with traditional instruments. The terms "3D anthropometry" and "digital anthropometry" have been used by researchers based on such systems to separate their methods from conventional manual measurement techniques.[20–22]

Importance of a Normative Anthropometric Database

Normative anthropometric data can be used in the diagnosis, treatment planning, and monitoring of patients with craniofacial deformities.

Diagnosis

Quantification of dysmorphology is performed by comparing patients' anthropometric measurements to their race- and gender-specific metric norms. As considerable ethnic differences exist in these norm values,[23] race specific normative data are important for precise determination of the degree of facial dysmorphology. By comparing patients' anthropometric measurements and proportions with age- and gender-matched norms of the particular race/ethnicity it is possible to identify the following:

1. Presence or absence of deformity
2. Extent of deformity
3. Location/size of the deformed region
4. Most defective sites /measurements
5. Other minor defects not clearly visible but potentially of significant diagnostic value[5]

Consequently, patterns of dysmorphology can be recognized by retrospectively analyzing data from several patients with similar clinical features.[5] Therefore, standardized diagnostic criteria for common craniofacial deformities could be derived based on anthropometry.

Treatment Planning

The ideal aim of surgery should be to reconstruct the facial appearance to match the population mean of the corresponding age, gender, and ethnicity. Hence, knowledge of the mean and standard deviation (SD) of key facial measurements are invaluable when deciding on the extent, type, and the timing of surgery.

Employing preoperative anthropometric data, surgeons can identify those factors during treatment planning. Required changes can be calculated by using normal measurements as indicators of the appropriate amount of change required to correct disproportions.

Postoperative Evaluation

Variations in linear or angular anthropometric measurements and proportions could be used to compare preoperative and postoperative 3D images. Success and long-term stability of surgery can be evaluated by prospective 3D anthropometric measurements. The surgical outcome might then be considered a success, if a marked reduction in the degree of abnormality compared with normal anthropometric proportions can be achieved.[17]

Table 1 Some of the landmarks used in manual anthropometry

Region	Name	Abbreviation	Definition[5,17]
Head	Vertex	v	The highest point on the head when the head is oriented in the Frankfort horizontal plane
	Trichion	tr	A point at on the hairline in the midline of the forehead
	Glabella	g	The most prominent midline between eyebrows
Nose	Nasion	n	The midpoint on the soft tissue contour of the base of the nasal root at the level of the frontonasal suture
	Sellion	se	The most posterior point of the frontonasal soft tissue contour in the midline of the base of the nasal root
	Pronasale	prn	The most anterior midpoint of the nasal tip
	Subnasale	sn	The midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip
	Alare	al	The most lateral point on each alar contour
	Alar curvature (or alar crest) point	ac	The most lateral point in the curved baseline of each ala
	Columella apex	c′	The most anterior, or the highest point on the columella crest at the apex of the nostril
Eye	Exocanthion	ex	The soft tissue point located at the outer commissure of each eye fissure
	Endocanthion	en	The soft tissue point located at the inner commissure of each eye fissure
	Palpebrale superius	ps	The highest point in the mid portion of the free margin of each upper eyelid
	Palpebrale inferius	pi	The lowest point in the mid portion of the free margin of each lower eyelid
Lips and mouth	Labiale superius	ls	The midpoint of the vermilion line of the upper lip
	Crista philtri	cph	The point at each elevated margin of the philtrum just above the vermilion line
	Cheilion	ch	The point located at each labial commissure
	Stomion	sto	The midpoint of the labial fissure when the lips are closed naturally
	Labiale inferius	li	The midpoint of the lower vermilion line
Chin	Sublabiale	sl	The midpoint of the Labiomental sulcus
	Pogonion	pg	The most anterior midpoint of the chin
	Gnathion	gn	The lowest median landmark on the lower border of the mandible
Ears	Tragion	t	The notch at the upper margin of the tragus
	Otobasion inferius	obi	The point of attachment of the ear lobe to the cheek
	Otobasion superius	obs	The point of attachment of the helix in the temporal region
	Postaurale	pa	The most posterior point on the free margin of the ear
	Preaurale	pra	The most anterior point of each ear, located just in front of the helix attachment to the head
	Superaurale	sa	The highest point of the free margin of the auricle
	Subaurale	sba	The lowest point of the free margin of the ear lobe

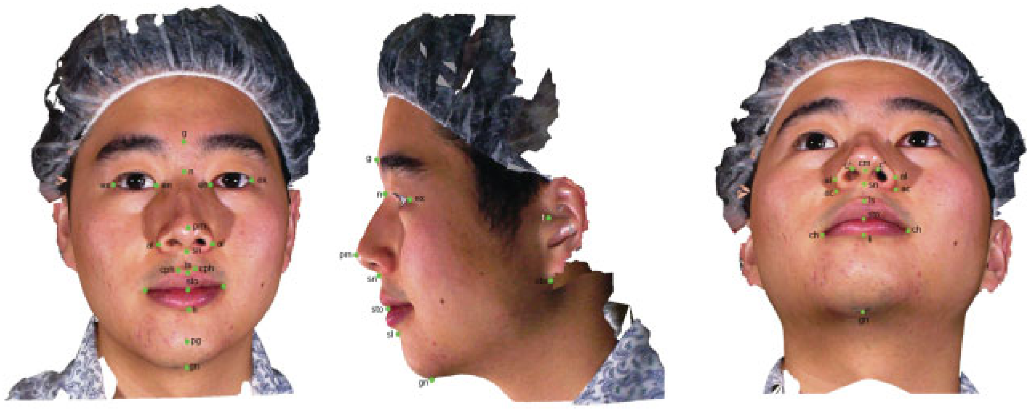

Figure 2 Some of the landmarks used in digital anthropometry (please refer to ►**Table 1** for definition of these landmarks).

Z-scores (Standardized Scores)

When assessing facial deformities, it has been customary to apply Z-scores instead of the linear and angular anthropometric measurements.[24] The individual "raw" measurements obtained from each subject is standardized through the conversion to Z-scores by (1) deducting age, gender, and race specific mean value for the reference group from the patient's measurement and (2) dividing it by the standard deviation (SD) of the reference group[24]:

$$z = \frac{x - \mu}{\sigma}$$

where x is the patient's measurement; μ is the average of the reference group; andσ is the SD of the reference group.

A Z-score reflects how many SD's above or below the reference mean a particular person's datum lies. As the Z-score scale is linear, it is possible to calculate summary statistics such as the mean, median, SD, or standard errors for a given Z-score distribution as well as to compare these scores between different groups.[25] The World Health Organization (WHO) states that the SD of Z-scores can be used as a measure of the quality on anthropometric data related to growth (e.g., height, weight, and body mass index) as it is reasonably constant across populations regardless of nutritional status.[26]

A positive Z-score indicates that the particular datum is larger than the average of the reference group. Likewise, a negative Z-score suggests that the datum is located several SD's below the reference mean. The Z-scores provide a standardized method for expressing individual differences devoid of the influence of gender, age, or race. It is possible to define normal and abnormal measurements or proportions based on the Z-score by applying statistical cutoff points[17]:

- Normal = Average Z-score ± 2SD
- Abnormal
    - Subnormal = Average Z-score – 2SD
    - Supernormal = Average Z-score + 2SD

The average Z-score for all individual facial anthropometric measurements of a given subject is called "Mean-Z" and can be considered as an overall estimate of the size of the face.[27] A highly positive Mean-Z is indicative of a large face while a highly negative Mean-Z is suggestive of a small face.

Other Applications of Three-dimensional Anthropometry

Growth Studies

Information on growth characteristics are also required to decide on the extent and the timing of surgery. It is crucial that surgical corrections do not impede growth. As growth patterns vary in each region of the craniofacial complex, surgery should be avoided in those regions, which are in periods of accelerated growth.[13]

The effect of relapse and growth must be differentiated when monitoring long-term postsurgical changes. Thus, data on normal as well as abnormal growth patterns are necessary during treatment planning. Such information can be collected by longitudinal growth assessment of craniofacial structures using 3D anthropometry.

Anaplasthology

It is possible to combine 3D anthropometry and computer-aided design and computer-aided manufacture technology to fabricate maxillofacial epistheses for patients after tumor resection. The traditional method of constructing facial prosthesis requires at least two impressions of the facial defect. Such procedures can distress patients and are very laborious for clinicians. 3D images eliminate the need for repeated facial impressions and provide a "virtual cast."[28] Unaffected regions of the face could be used as templates with the mirroring technique.[29] In case of bilateral defects, anthropometric information from the unaffected side or population norms could be used for molding the epistheses. The dependence on the artistic ability of the technician can be minimized as 3D images provide excellent information on surface contour, color, and texture.

Forensics

Recordings from video surveillance systems are increasingly being used for the identification of suspects. Anthropometric measurements and proportions from these video images are compared with manual measurements from the suspect to establish a positive identification and conviction.[30,31]

Anthropometric norms are also useful to predict current facial profiles of missing persons as well as to identify and estimate the age of skeletal remains.[2] Existing techniques used for forensic reconstruction of facial soft tissues on skeletal remains rely on data collected from adult cadavers in the last century.[2] The use of such old cadaveric data, however, bears several shortcomings:

- Soft tissues undergo changes subsequent to death.
- Destitute cadavers have been used in most of these early studies whose nutritional and health may not represent the population as a whole.
- Gravitational forces may cause false soft tissue measurements in horizontally positioned cadavers.[32]

Thus, race- and gender-specific facial norms are of value for forensic reconstructions and identification of missing persons.

Genetics

Early diagnosis of congenital anomalies enables the clinicians to provide best possible care to patients and their families. Anthropometry is being utilized as an objective method for phenotypic assessment in clinical genetics.[11] As syndromes have comparable phenotypes, that is, patterns of traits, anthropometric techniques can be used for detecting both new syndromes and genotypic–phenotypic correlations of established syndromes. Such association studies between specific facial features and genetic variants permit a better understanding of their etiopathogenesis as well as the relationship between physical anomalies and facial appearance.[33] Adult anthropometric norms can also be used for identification of individuals who do not show the entire clinical manifestation of underlying genetic diseases. Such advanced detection of individuals at risk of dormant systemic conditions facilitates genetic counseling.

Ergonomic Product Design

The field of ergonomics is focused on the study and designing equipment/devices that accurately fit the human body. Therefore, anthropometric data about the craniofacial region are valuable to ensure accuracy between the designed products and target customers. For example, race-specific anthropometric data have been used to evaluate the compatibility of air purifying respirators,[34] spectacles,[35] and helmets.[36]

Conclusion

Anthropometry has been traditionally used as a research tool. With the advent of digital anthropometry, this technique can be employed in several disciplines as a noninvasive tool for quantifying facial morphology.

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