

Cranio-Mandibular Parameters of Lateral Cephalometric Radiograph to Determine Sex in Forensic Investigations: An Electronic Search Study

Darshan Devang Divakar^{1*}, Jacob John², Abdulaziz Abdullah Al Kheraif¹,
Ravi Kumar Ramakrishnaiah¹, Seema Mavinapalla³ and Obaid Abdullah Alshahrani⁴

¹Dental Biomaterials Research Chair, Dental Health Department, College of Applied Medical Sciences, King Saud University, Riyadh 11433, Kingdom of Saudi Arabia

²Professor, Department of Orthodontics, K.V.G Dental College and Hospital, Sullia, Karnataka, India

³Lecturer, Department of Oral Medicine and Radiology, KVG Dental College and Hospital, Sullia, Karnataka, India

⁴Dentist, KSU, Alfarabi Colleges, Kingdom of Saudi Arabia

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ABSTRACT Skeletal components play a significant role in sex determination in forensic investigation. The skull is considered second best, after the pelvis, in determination of sex. Methods based on morphological characteristics and morphometry are already in use with reasonable accuracy. Standardized radiographic techniques like cephalometry have advantages of being more precise and objective when compared to morphologic methods. The present electronic search study was to evaluate the importance of cranio-mandibular parameters of lateral cephalometric radiograph to determine sex in forensic investigation. In this study an electronic literature search was performed for articles and books published between January 1962 and December 2014. As a result, only 40 literatures were found, out of which only 14 publications (12 articles and 2 book) were relevant to the searched topic. To conclude, this study has shown that the cranio-mandibular parameters of lateral cephalogram plays an important role in determining sex for forensic investigation and diagnosis.

INTRODUCTION

“The dead cannot cry out for justice, it is the duty of the living to do so for them” - *Lois Me-Master Bujold*.

Identity is the set of physical characteristics, functional or psychic, normal or pathological that defines an individual. Historically, human identification is one of the most challenging subjects that man has confronted (Paiva 2003). The four main attributes of biological identity that most forensic investigators hope to determine are the sex, age, stature, and ethnic background of the individual (Scheuer 2002). Additional points, which can be used in case of identification of deceased person are, complexion, feature, hair, anthropometry, dactylographic pattern, deformi-

ty, occupational marks and DNA profile (Modi 1988).

The differentiation of sex in the forensic or anthropological research context is keystone to establish a biological profile of human remains (Scheuer 2002). Non-mutilated remains do not pose any difficulty in the identification, thereby the challenge lies in identifying mutilated body parts when only a part of skeleton or bone is found. If the entire skeleton is available, sex can be assessed often with a hundred percent accuracy. Various skeletal components, which have given good results, are the pelvis, skull, thorax, vertebrae, femur and scapula (Modi 1988; Ahsen et al. 2014). After the pelvis, the skull is the most easily sexed portion of the skeleton, but determination of the sex from a skull is not reliable, as it is only after puberty that the secondary sexual characters emerge (Biggerstaff 1977). Sexual dimorphism exhibited by the skull is mainly dependent on changes that occur in the male at puberty that reflect prominent muscular attachments, whereas the female skull tends to retain pedomorphic features (Scheuer 2002).

Out of all morphological differentiating features that have been described for gender dif-

*Address for correspondence:
Dr. Darshan Devang Divakar
Dental Biomaterials Research Chair,
Dental Health Department,
College of Applied Medical Sciences,
King Saud University, Riyadh 11433,
Kingdom of Saudi Arabia
Telephone: +966538038291
E-mail: darshandevang@gmail.com

ferentiation in the skull, unfortunately no single feature is characteristic. As the cranio-facial structures are majorly composed of hard tissues, which are relatively unyielding, therefore they have the advantage of helping with differentiation between individuals and population groups (Biggerstaff 1977).

Conventionally, sexing of the skull is based on morphological or anthropometric analysis with accuracy ranges of about seventy-seven to ninety-two percent. As only a constellation of diagnostic traits permit sexing of the adult skull, there can be alterations in the above-mentioned range (Biggerstaff 1977; Krogman 1962). The level of sexual dimorphism in the population under consideration differs from those in the standard for comparison (Scheuer 2002). The accuracy of determination depends on which particular elements of the skull are present and also on their state of preservation. The experience of investigator in the field dictates the reliability (Scheuer 2002; Biggerstaff 1977). Considerable inter-investigator variability has been reported in determination of the sex using morphological characters of the skull. These generalities are not absolute and must be tempered with the cultural constraints of the population (Biggerstaff 1977).

Radiographs in this regard provide a more precise, easier and accurate method for determining sex by linear and angular measurements. They also help minimize inter-investigator bias (Ahsen et al. 2014; Hsiao 1996). Various studies have concluded that, the identification of sex by skull radiograph is a reliable method with an accuracy of up to eighty to hundred percent. This accuracy can be further enhanced by standardized skull radiography such as lateral and postero-anterior cephalometric views, as they can provide architectural and morphological details, thus revealing additional characteristics and multiple points for comparison (Biggerstaff 1977; Patil 2005).

Cephalometry can be used for the standardization of cranio-facial parameters of a given population. The lateral cephalometric radiograph reveals architectural details of the cranium, facial components like maxillofacial bones, nasal, orbital and various paranasal sinuses, whereas postero-anterior view offers features like facial height, width in frontal profile (Biggerstaff 1977). Determination of sex, while well established for many populations yet a population specific phenomenon (Iskan 2005), but modern researches'

yield the fact that human populations are ambiguous and cannot be divided into clearly defined, biologically distinct groups. The classical three-race model has been discarded, hence suggesting that the concept of race should be dropped altogether, whereas others propose an "ethnic group" as a more accurate term for human population differences (American Anthropological Association Statement 1998).

MATERIAL AND METHODS

Literature Search Design

An electronic literature search was performed for articles and books published from January 1962 to December 2014. The articles were selected on the basis that they are from reputed Journals indexed in the ISI Web of Knowledge, PubMed or Medline, and having a good impact factor and Eigen factor score.

RESULTS

As a result only 40 literatures were found suitable, out of which only 14 publications (12 articles and 2 book) were found relevant to the searched topic and meeting the criteria.

DISCUSSION

To the best of the researcher's knowledge, this is the first electronic study done in this way to understand the importance of cranio-mandibular parameters of lateral cephalometric radiograph to determine sex in forensic investigations and compiled into one well-informed article.

Sex determination of human remains forms the corner stone in biological profile. Conditions like natural or manmade mass disasters, genocides or aircraft crash accidents result in situations where direct or positive identification of the victims is difficult, as the bodies get decomposed, dismembered or extremely burned. It is here that osteological criterias plays a major role for sex determination as a first mode in indirect identification. The skeletal components consist of hard tissue, which may escape or sustain such extreme conditions yet restrain valuable information.

Reasons for Sexual Dimorphism in Bone

The sexual dimorphic variations begin to develop during the inutero life itself, which later represent as differences in the bone weight,

length, size and bone mineral density. The significant factors, which play a role in dimorphic features are:

1. Role of Growth Spurts and Growth Patterns

Skeletal sex determination relies on dimorphic expression of bony characteristics produced through different patterns, rates and periods of adolescent growth. Males having both a longer and more intense adolescent growth spurt than females, thus extended growth pattern creates difference in size that can be measured empirically or gauged relatively. That can be classically seen in the skull, where the growth spurts affect most of the structures.

2. Muscular Attachments to the Bones

These give an important edge. The difference in physical activity, nutritional conditions along with genetic, environmental and hormonal factors play a vital role in sexual dimorphism. This holds true especially for the long bones, pelvis, chest and vertebrae.

A more important aspect is the pubertal changes in the bones. The secondary sexual changes are influenced by hormones, which play a role in the development of the general musculoskeletal system. The secondary sexual characteristics emerge at adolescence, which are seen earlier and for a shorter period in girls, compared to boys, who undergo pubertal changes 2 to 3 years later, but sustain them for a longer period. In immature bones the dimorphic features are not well evident to aid inaccurate differentiation unlike bones in adults of the age group of 25 to 55 years. With senile changes, the features show lesser accuracy. Various bones, which are used as a tool in sexual dimorphism, are the pelvis, skull, long bones, scapula and clavicle (Krogman 1962).

Methods of Skeletal Assessment for Sexual Dimorphism

Skeletal sex can be established using either morphological or metric techniques. Although there is some overlap between the two techniques, they should be used in conjunction to produce the most accurate and complete assessment of sexual dimorphism. This is particularly critical for individuals whose skeletal dimensions

and characteristics do not lie at the extremes of sexual dimorphism.

Morphological techniques are based on categorizing a given sample through analysis of visually assessed trait. These traditional methods provide a 'first sight' impression. A large skull, that is robustness, indicates male character while females have a smaller skull. In these methods, accuracy in sex determination depends largely upon the examiners' familiarity with the population being studied. Traits that are sexually dimorphic in one population may be much less so in another. The positive aspect of this method is the ability to measure in case of fragmented or poorly preserved bones with fairly good accuracy.

Metric methods have several benefits when compared to morphological techniques. They are considered objective because they rely on standard landmarks, are easy to teach, learn and reproduce, result in lower levels of intra/inter-observer errors, thus produce fewer indeterminate results (Krogman 1962).

As a group, metric analyses suffer from two major limitations. They are difficult to apply on fragmentary material, because most formulae depend on measurements of several intact bones and/or dimensions that span multiple bones. Secondly, population differences in bone length and body proportion restrict the application of metric techniques to the population on which they were developed and tested. Thirdly, in the statistical based osteometric techniques, data collection is time consuming and often requires specialized and expensive anthropometric equipment. These also require devices that accurately capture and measure subtle, visually apparent, sexually dimorphic shape variations. Thus, both metric and morphologic techniques have inherent positive and negative aspects such as,

1. Both techniques cannot give reliable accuracy in case of sub-adult skeleton.
2. Chances of incorrect identification are more with female skulls through both methods.

Role of Skull Morphology in Sexual Dimorphism

Development of the cranium is influenced by the growth of the neurocranium. Cranial characteristics such as larger male brow ridges, eyes appearing lower in the face, and larger nasal apertures, are a result of extended normal downward and forward growth of the male face rela-

tive to the female face. This is due to more intense and extended male growth spurts. A review of cranio-facial growth reveals three key points relating to the expression of sexually dimorphic features of the skull.

1. The greatest relative growth from childhood to adulthood is seen in the mandible, maxilla, upper face, cranial base and head height.
2. The neurocranium is the earliest growing region of the skull, followed by the mid-face and parts of the cranial base, last to develop are structures relating to mastication.
3. In the skeleton, parts, which grow earlier, are typically less sexually dimorphic than those, which develop later. Also, longer the period of growth the more pronounced are the changes.

The growth of female facial features begin to slow around 13th year of life and maturation is completed soon afterward, while males enter a growth spurt that continues through adolescence with maturation completed in early adulthood. The cranio-facial proportions are about the same, although the female the facial skeleton may be relatively more gracile. Owing to individual variations, certain amount of overlap in size of male and female facial features is inevitable (Hsiao 1996).

Populations may show sexually dimorphic changes in the cranial size and shape over timespans as short as few decades. Hence, it is essential to assess the parameters for temporal changes.

Morphologic traits, which have significant sexual dimorphism with *higher strength*, are:

- ♦ Mastoid process
- ♦ Glabella and supraorbital ridges
- ♦ General size and architecture
- ♦ Malar (zygomatic) prominence
- ♦ Nasal aperture
- ♦ Mandible (mental prominence and gonial angle)

While traits which are significant with *lesser strength* are:

- ♦ Frontal and parietal prominence
- ♦ Occipital region (external occipital prominence)
- ♦ Forehead (in frontal profile)
- ♦ Palate and teeth

The strength of a given character can be explained as the confidence level with which it can be categorized among the given groups. For a

given sample, the sexual categorization is done by taking the above-mentioned characters as a group and based on their strength. This is so because any single character cannot be relied with a hundred percent accuracy in case of an adult skull. This holds true for both morphologic and morphometric techniques (Hsiao 1996).

Role of Radiology

Radiology has played a profound role in the understanding of anatomical and pathological aspects of the skeleton. Regarding radiology it has been quoted that 'it is the place where rays delight to help the living'. It has also found to have a role in forensic medicine. They have provided vital information regarding age, sex percentage and racial identity.

Identification based on skeletal radiographs is done via two methods. Ante mortem radiographs when available, can be used for match identification. On the other hand, radiographs of skeletal remains can be used for indirect or negative identification, which means that a probable identity of age, sex, stature and ethnicity is made based on radiographs and which can be later confirmed with sophisticated methods like a DNA analysis. The latter method of indirect identification using radiographs is based on metric techniques, which use linear and angular measurements, ratios or proportions (Hsiao 1996).

Skull Radiography in the context of forensic identification is a time-tested method. The lateral and postero-anterior views illustrate cranio-facial structures, which have a significant role in sex, age and racial differentiation. Limitation lies in the fact that radiographs can depict 2-dimensional views of 3-dimensional body structures (Naikmasur 2010).

Physical anthropologist initiated craniometry or cephalometry for morphometric assessments of the skull. Radiographic cephalometry was introduced into orthodontics by Broadbent and Hofrath in 1931. This new technique had played an imperative role in clinical and research orthodontics as well as in the entire field of research of cranio-facial growth. The cranio-facial research advanced from craniometry (measuring the dry skull) or cephalometry (measuring the living skull) to radiographic cephalometry (measuring the tracing of a radiographic film of head).

The lack of standardization in conventional skull radiographic techniques posed a signifi-

cant hindrance for their use for linear and angular measurements in metric techniques. A slight tilt or rotation of the skull may obscure or affect the observatory findings. Thus cephalometry was tried in the forensic field. In this technique, essentially the skull position is fixed using a ear rod device, which prevents rotation along the transverse and axial axis, while a forehead bar prevents tilting in coronal plane. The lateral and PA cephalometric analysis have shown significant sexual dimorphic features. These are due to dimorphic differences in the development of the craniofacial region. The expression of craniofacial features is in part a function of time, unfolding primarily during the period of growth and development. With respect to observations made on craniofacial growth, pertaining to sexual dimorphism, following points are of considerable importance:

1. Cranial base length
2. Facial height
3. Facial depth
4. Maximum facial width
5. Mandibular length and height
6. Bicondylar width
7. Facial width at angle, and
8. Symphyseal height

Cranial Base Length

Linear dimensions of the human skull are significantly greater in males than females. The cranial base (Nasion to Basion) can be divided into two parts (as viewed from the lateral aspect).

1. Anterior cranial base (Sella to Nasion)
2. Posterior cranial base (Sella to Basion)

The growth of the anterior cranial base largely depends upon the anteroinferior growth of naso-maxillary complex and sphenoid region, while the growth of the posterior cranial base depends on the temporal bone and the mandible. Males usually have prominent muscular activity attached to these bones, which will lead to more outward and downward direction of growth for these bones, along with a compensatory mid-facial region that develops proportionately, thus leading to an increase in the entire length of the cranial base. By this way the cranial base length will help in dimorphic differentiation (Antoaneta 2014).

Facial Height

The total facial height (Nasion to Menton) depends upon skeletal growth pattern of maxilla

and mandible, occlusion status and muscular activity. Usually for individuals with dentulous normodivergent pattern, the relative growth of the jaws and muscular activity provide sexual dimorphic features. The nasal and maxillary areas undergo high levels of relative growth, and are intermediate to late growing regions of the face. As males sustain a longer growth spurt, the nasomaxillary complex will grow more and may lead to longer upper facial height (Nasion to Anterior Nasal Spine). They also have high muscular activity and long teeth size. Thus, lower facial height (Anterior Nasal Spine to Menton) will also have dimorphic features (Naikmasur 2010).

Facial Depth

This in turn reflects growth of the face in the anteroposterior direction. The prominent muscular activity, especially by the masseter, will affect the ramus width. Nasomaxillary region under the influence of longer growth spurts will be longer for males. As expected cranial base is also proportionately larger in males, thus the facial depth (Basion to Anterior Nasal Spine) shows sexual dimorphism due to the combined effect of muscular activity, cranial base lengthening and growth of nasomaxillary region.

Maximum Facial Width

This region expresses width at zygomatics (Zygomaticus to Zygomaticus). This can be appreciated in a frontal profile. Bizygomatic width reflects the growth at the maxilla and orbital region in lateral direction. Relocation of the malar bone posteriorly during growth combined with lateral growth of the zygomatic arch and remodeling causes the temporal fossa to enlarge, while the malar bone remains proportionately broad in relation to the face, jaw size and masticatory musculature. Extended growth in males causes the malars to be large and the zygomatic arch to be displaced more laterally than the corresponding structures in the females. Thus males have a definitely larger width, providing robustness in male facial skeleton. This feature is significant which has been applied in both morphological and morphometric assessments (Antoaneta 2014).

Mandibular Length and Height

The mandible is the largest and strongest bone in the face. The shape of the mandible can

vary according to the different lifestyles and chewing habits. There are many reasons, which contribute to the variation in shape and size of the mandible between the sexes (Florentin 2009; Mihai 2013). The shape and size of the mandible appear to differ between the sexes mainly due to the development of deciduous tooth bearing alveolus and size of masticatory muscles. Mandible appears to have dimorphism before birth. The size of ramus differs between males and females according to the stage of mandibular development and muscle growth. Furthermore, mandible grows at a different rate in males and females. Because puberty occurs earlier in females than in males, sexual differences may manifest themselves in the skull and jaws of females earlier than in the males who mature later and for longer. Mandibular height (Articulare to Gonion) and length (Gonion to Menton) depends directly on skeletal growth pattern of jaws and indirectly on cranial base, muscular activity and dentition (Florentin 2009; Mihai 2013).

Bicondylar Width

This region (Condylion to Condylion) shows dimorphism between sexes due to a difference in cranial base lengthening, lateral expansion pattern and muscular activity. This also develops later in adolescence (Mihai 2013).

Facial Width at Angle of Mandible

Mandibular gonial region has a predominant muscle activity. The overall activities of masticatory muscles make the region to be one of the strongest bony parts of the entire skeleton. The strong muscle activity in the males causes flaring of the gonial region, thus providing a facial width at the angle region (Gonion to Gonion), a prominent dimorphic feature of the mandible (Naikmasur 2010).

Symphyseal Height

The symphyseal height (Infradentale to Menton) is usually higher in males due to a broader chin size and shape. The later development of lower facial form also provides additional factors for dimorphism.

Thus, the above-mentioned criteria should be taken as significant differentiating features while using standard radiographic method like

cephalometry for adult age group individuals as sexual dimorphic features.

CONCLUSION

It can be concluded that cranio-mandibular parameters contribute to sex prediction in populations. Strong studies are required to assess the significance of linear and angular cephalometric cranio-mandibular parameters for sex discrimination in various populations.

RECOMMENDATIONS

This electronic literature search study has shown that specific osteometric standards for sex assessment from lateral cephalometric radiograph exists and are important and useful. Further research on different populations may provide additional accurate standards with numerical values that may help in identifying the sex better and in solving many medico-legal cases.

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