Original research

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Anthropometric analysis of mandible: an important step for sex determination

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Abstract

Introduction. The first step in the forensic identification is sex determination followed by age and stature estimation, as both are sex-dependent. The mandible is the largest, strongest and most durable bone in the face. Mandible is important for sex confirmation in absence of a complete pelvis and skull.

Aim. The aim of the present study was to determine sex of human mandible from morphology, morphometric measurements as well as discriminant function analysis from the CT scan.

Materials and methods. The present retrospective study comprised 79 subjects (48 males, 31 females), with age group between 18 and 74 years, and were obtained from the post mortem computed tomography data in the Hospital Kuala Lumpur. The parameters were divided into three morphologic and nine morphometric parameters, which were measured by using Osirix *MD* Software *3D* Volume Rendering.

Results. The Chi-square test showed that men were significantly association with square-shaped chin (92%), prominent muscle marking (85%) and everted gonial glare, whereas women had pointed chin (84%), less prominent muscle marking (90%) and inverted gonial glare (80%). All parameter measurements showed significantly greater values in males than in females by independent t-test ($p< 0.01$). By discriminant analysis, the classification accuracy was 78.5%, the sensitivity was 79.2% and the specificity was 77.4%. The discriminant function equation was formulated based on bigonial breath and condylar height, which were the best predictors.

Conclusion. In conclusion, the mandible could be distinguished according to the sex. The results of the study can be used for identification of damaged and/or unknown mandible in the Malaysian population. **Clin Ter 2018; 169(5):e217-223. doi: 10.7417/CT.2018.2082**

Key words: *Mandible, morphology, forensic, three-dimensional computed tomography, identification*

Introduction

Skeleton is one of the important elements in genetic, anthropological, odontological as well as forensic investigation in living and non- living individuals (1). In forensic cases, identification of human remains is the most important step for further investigations (2). Identification of sex is the most crucial aspect in anthropological examination as its knowledge immediately eliminates half of subsequent police investigation probabilities. Furthermore, the methods of age and stature estimation depend on correct sex determination (3).

Sex can be determined up to 100% accuracy with the entire adult bone analysis (2). However, in the most challenging task for forensic experts such as mass disasters, explosions and air hurricanes cases, where usually only fragmented skeleton are detected, 100% accuracy of sex determination is impossible (2,4).

According to previous studies, following pelvis, the skull is believed to be the most dimorphic and easily sexed portion for differentiation of skeleton, providing 92% accuracy (2). Mandible plays a vital role in sex determination when the intact skull is not found (4-6). Mandible is also an important tool in the determination of gender because of its high accuracy (7). The mandible is the largest and strongest bone in the face, which comprised body, rami, coronoid and condylar processes. There are four muscles of mastication namely masseter, medial and lateral pterygoid and temporalis that attach and produce movement of the mandible (8).

Both qualitative and quantitative methods have been used for distinguishing sex, age and race (9). One of the earliest approaches in forensic case in sex determination is by examination of the bone morphology. Sex determination has been reflected by the shape and size of the mandible, and male bones are generally bigger and robust than females (4). Using non-metric methods, researcher found that the shape of chin could be used to distinguish between males and females (10).

Regarding sex determination methods, discriminant function analysis has gained good success rate. The accuracy rates obtained were better than those based only by visual assessment and classic measurements, varying from 83 to 88 percent for crania and 92 to 98 percent (and even

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100%) for pelvic bones, respectively (11-14). A more recent series of studies have shown that discriminant function is population-specific (15-18). Therefore, the best accuracy for any discriminant function may be obtained by using population-specific methods by national standards.

In this respect, over the following years, many researchers have computed population-specific discriminant functions in order to maximize the accuracy rates for sex determination on unknown skeletal remains (19-21). Therefore each population requires the development of population-specific standards for accurate sex determination for a skeleton derived from that population. Previous studies have been conducted on mandibles using traditional anthropological methods, as well as modern imaging methods (22-23). Radiography is a less invasive method, which can be employed in both living and dead individuals (24). Anthropologically, CT has been utilized in the study of skulls, and also in the forensic context as an additional resource in the process of identification. The aim of the present study was to determine sex of human adult using mandibular morphology and discriminant function analysis using 3D-CT in the Malaysian population.

Materials and Methods

This retrospective study was conducted at Hospital Kuala Lumpur. The database was collected from postmortem computed tomography (*PMCT*) images retrieved from the Department of Forensic Medicine, Hospital Kuala Lumpur. The sample comprised all individuals with documented sex, race and age received by the mortuary for four years duration from January, 2012 till June, 2016. About 79 dentulous mandibles were obtained (48 males, 31 females) with age ranged between 18 and 74 years.

All intact and well-formed, adult mandibles were sampled. All pathological, edentulous, deformed or broken mandibles were excluded from the study. The morphology of mandible was described accordingly, while morphometric measurements of mandible were measured on the right side of mandible by using Osirix *MD* software from *3D* Volume Rendering. The measurements in centimetres (cm) were rounded off to the nearest 2 decimal places. The discriminant function analysis was done using morphometric measurement by *SPSS* software version 23. The study was approved by the Medical Ethics Committee, Faculty of Medicine, UKMMC (*UKM PPI/111/8/JEP-2016-359*).

Morphologic parameters (25)

There were three morphologic parameters observed.

i. Shapes of squared chin in males and pointed chin in females; ii. Gonial flare with either everted as in males or inverted as in females; iii. Muscle markings with more prominent markings in males than in females.

Morphometric parameters (25-27).

There were 9 morphometric parameters as described below:

i. Maximum breadth of ramus (*MAXBR*)– the distance between the most anterior point on the mandibular ramus and a line connecting the most posterior point on the condyle; ii. Minimum breath of ramus (*MINBR*)-Smallest anterior–posterior diameter of the ramus; iii. Condylar height (*CNH*)-Height of the ramus of the mandible from the most superior point on the mandibular condyle to the tubercle, or most protruding portion of the inferior border of the ramus. iv. Maximum height of ramus (*MAXHR*) – the distance between the midpoint of mandibular notch to the angle of mandible. v. Coronoid height (*CH*)- Projective distance between coronion and lower wall of the bone; vi. Mandibular Body Height (*MBH*)– The direct distance between the alveolar process to the inferior border of the mandible perpendicular to the base at the level of mental foramen. vii. Symphyseal height (*SH*)– The direct distance between alveolar process to the inferior border of the mandible perpendicular to the base at the level of symphysis menti; viii. Bicondylar Breadth (*BCB*)- The straight distance between the most lateral points on the two condyles; ix. Bigonial Breadth (*BGB*) – The straight distance between two gonia.

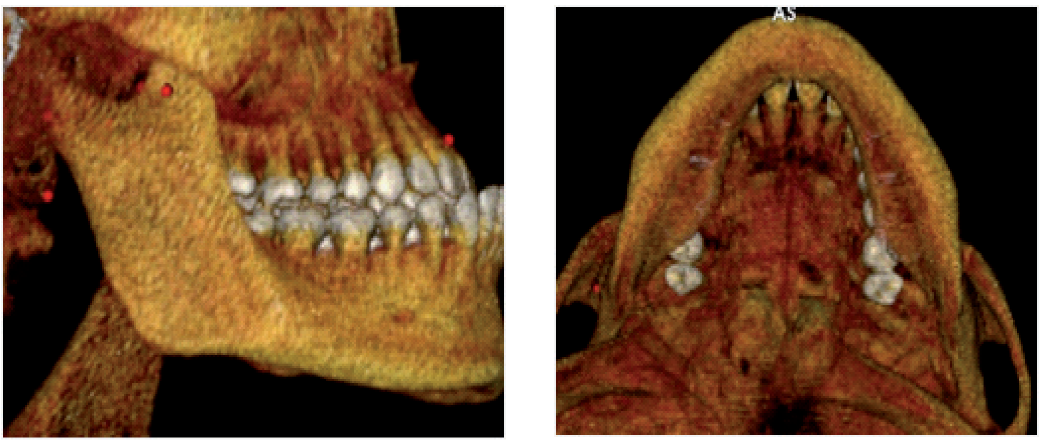

Fig. 1. PMCT of mandible.
(a- Prominent muscle marking, b - square shape of chin and everted gonial glare (arrow)

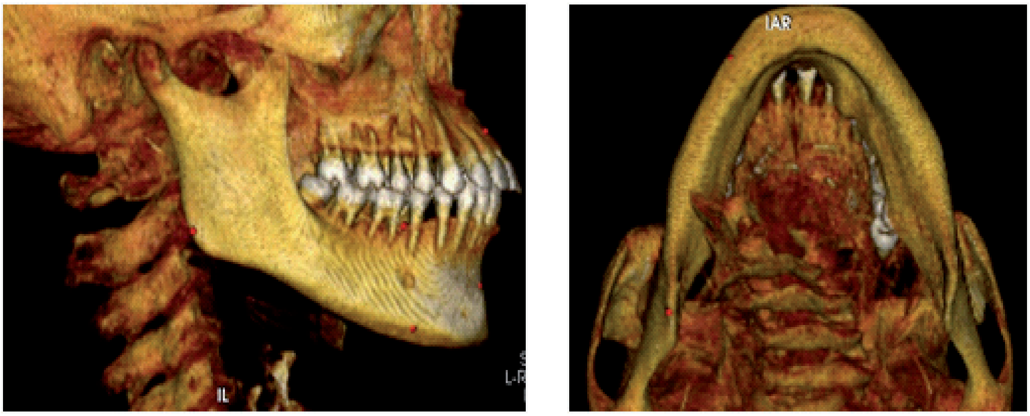

Fig. 2. PMCT of mandible.
(a- Not Prominent muscle marking , b - Pointed chin and inverted gonial glare (arrow)

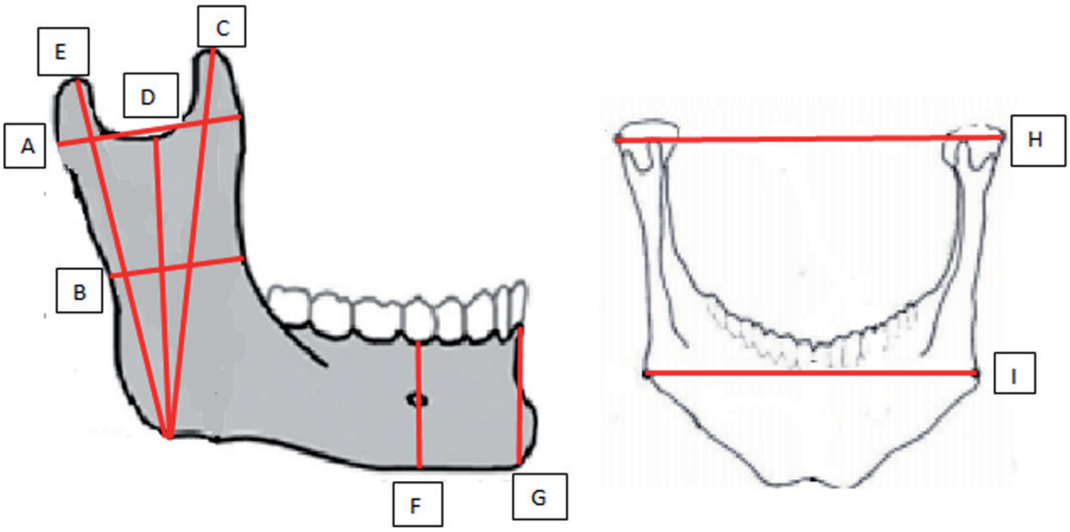

Fig. 3. Diagram showing mandibular ramus measurements adapted from Saini et al (2)

Discriminant function analysis was done using nine morphometric parameters.

Statistical analysis

The independent *t*- test was used to compare between males and females, while Chi-square test was done to evaluate the association between morphologic variation of mandible and sex. The discriminant function was used to compare between different sex, and formulate the equations. The data were analysed using *SPSS* version 23 (28).

Results

Results from the Chi-square test showed that males significantly correlated to squared chin (92%), prominent muscle marking (85%), and everted gonial glare (85%), whereas females mostly had pointed chin (84%), less prominent muscle marking (90%) and inverted gonial glare (80%). ($p < 0.01$) (Table 1)

The independent t-test showed significant difference between males and females, as males were higher than females in all parameters (Table 2).

The significance of the multivariate test (Wilks' lambda) showed the model was a good fit for the data with significant level less than 0.01 (Table 3).

Discriminant function equation was formulated from the discriminant function coefficients (Table 4).

The discrimination function equation was:

$P = 0.1*BCB + 0.641*BGB - 0.173*MBH + 0.153*SH - 0.009*MAXBR + 0.049*MINBR + 0.099*MAXHR + 0.088*CH + 0.518*CNH$

P- Discriminant score; *BCB*- Bicondylar breath; *MBH*-

Table 1. Relationship of shape of morphology parameters in male and female.

Morphology Parameters		Sex		P value Chi square
		Male	Female	
1. Shape of chin	Square	44 (92%)	5(16%)	0.0001
	Pointed	4 (8%)	26(84%)	
2.Muscle marking	Prominent	41 (85%)	3(10%)	0.0001
	Not prominent	7(15%)	28(90%)	
3.Gonial glare	Everted	41(85%)	6(20%)	0.0001
	Inverted	7(15%)	25(80%)	

*$p < 0.05$, Chi-square test

The table 1 showed that there was a significant relationship between morphology parameters and sex.

Table 2. Multivariate test (Wilks' lambda)

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1	.655	30.720	9	0.001

*p < 0.05, the model is a good fit for the data.

Table 3. Standardized Canonical Discriminant Function Coefficients

	Function
	1
BCB	.100
BGB	.641
MBH	-.173
SH	.153
MAXBR	-.009
MINBR	.049
MAXHR	.099
CH	.088
CNH	.518

The discrimination function equation was:
DF=0.1*BCB+0.641*BGB–0.173*MBH+0.153*SH-0.009*MAXBR+0.049*MINBR+0.099*MAXHR+0.088*CH+0.518*CNH

Table 4.Wilks' Lambda (BGB and CNH) was the best predictors.

		Wilks' Lambda							
						Exact F			
Step	Entered	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	BGB	.770	1	1	77.000	23.006	1	77.000	.000
2	CNH	.664	2	1	77.000	19.254	2	76.000	.000

$P<0.05$, Wilks's Lambda test

Table 5. Standardized Canonical Discriminant Function Coefficients

	Function
	1
BGB	.723
CNH	.642

The discriminant function score was conducted as follows:
DF=0.723*BGB+0.642*CNH

Mandibular Body height; *SH*-Symphisis Height; *MAXBR*- Maximum Ramus Breath; *MINBR*- Minimum Ramus Breath; *MAXHR*- Maximum Ramus Height, *CH*- coronoid height; *CNH*-condylar height

By stepwise statistics, 2 best variables were selected in the analysis, *BGB* and *CNH*, and these variables were highly significant by Wilks's lambda (Table 5).

Standardized canonical discriminant function coefficient showed that *BGB* was the best discriminant predictor followed by *CNH* in that order.

The discriminant function score was conducted as follows:

$P=0.723*BGB+0.642*CNH$

In the present study, male centroid was 0.567, while female centroid was -0.874. The sectioning point was the mean of male and female centroids of the same function. To assign the case as a male or female, the product *P* (discriminant score) was compared to the sectioning point derived by the discriminant function. A value higher than the sectioning point was considered to be male, and the value below the sectioning point, was considered to be female (29-30). (Sectioning point: 0.565-0.874/2= -0.1545)

The discriminant score (*P*) for males was found to be greater than the sectioning point, while the discriminant score (*P*) for females were less than the sectioning point. In the original sample, the sensitivity was 79.2%, and the specificity was 77.4%. After cross-validation, the sensitivity and specificity were similar as in the original sample. Thus, there was a high sensitivity and specificity of the sample, in which the classification accuracy was 78.5% by discriminant analysis.

Discussion

Determination of sex and identity of remains are significant for forensic science, anatomy, forensic odontology, anthropology as well as paleontology (31). The differentiation of features between sex and ethnic groups can be done by observation of the bone morphology (32). Pelvis and skull were reported as the most reliable skeletal elements in the sexing of an adult. While the skull is the second most sexual dimorphism, which shows the variability in size and morphology (49), the pelvic area exhibits the greatest sexual dimorphism in skeletal system of human. Numerous studies for sexual dimorphism were conducted on femur (50), metacarpal (51) and carpal bone (52). Previous studies proved that mandible showed significant ethnic, racial and sexual differences (33). Morphological features as well as morphometric parameters of human mandible are useful in sex determination (34). Both methods have their own advantages and disadvantages. Previous researchers have concluded that morphological parameters were better in the determination of sex, but it depends on the observer's ability and expertise. On the other hand, morphologic parameters were believed to be more objective and reproducible, and have low intra- and inter-observer error, nevertheless they can be influenced by dietary habit, lifestyle and environment (35). Hence, in this study, determination of sex from morphologic and morphometric mandible were used to reduce the error in identification.

In general, male mandibles usually have prominent muscle markings, everted gonial angle, and squared chin, whereas female mandibles usually have less prominent muscle marking, inverted gonial angle and pointed chin (7). Duthie *et al.*, 2007 and Indira *et al.,* 2012 found that male bones were generally bigger and more robust (36, 37). These facts were comparable with our study. Many factors may affect the difference in size and shapes of mandible during the early stages of growth such as lifestyle, chewing habit, racial, genetic and regional areas (2, 39). For both sexes, the stages of mandibular development, growth rates and duration are distinctly different (40-42). In addition, masticatory forces exerted are different between males and females, which influence the shape of the ramus (43).

In this study, all parameters were found to be greater in male mandibles than in female with an overall accuracy of 78.5%. By stepwise discriminant function analysis, from 9 parameters, the bigonial breath (*BGB*) and condylar height (*CNH*) were the best parameters selected in the analysis. Standardized canonical discriminant function coefficient showed that bigonial breath was the best discriminant predictor followed by condylar height. The researchers around the world studied the metrical traits of the mandible and their reliability in sex determination, with accuracy results varying from 60 to 90% (44). Most of the authors have measured up to 5 to 7 parameters, and the studies were focussed on less than 5 parameters with an accuracy of sex determination varying between population. The accuracy of sex determination from mandible was 85% in American Whites and Negroes and 81.5% in South African Whites (45, 46). Dayal *et al.*, 2008 and Saini V *et al.,* 2011 found that mandibular ramus height was the best parameter with 76% accuracy (2, 47).

Humphrey *et al.,* 1999 pointed out that during growth, the mandibular ramus and condyle are the sites associated with the greatest morphological changes in size and remodeling, hence most dimorphic (48). This study also demonstrated the best combination of two parameters for determining the sex of mandible. Franklin D *et al.,* 2008 also concluded that the most dimorphic regions of the mandible were the condyle and the ramus (47, 48). Both results were comparable with our study. However, in the Croatian archaeological sample, maximum ramus breadth, minimum ramus breadth, and maximum ramus height were found to be highly significant for differentiation of sex in the study. This variation in classification accuracy clearly showed that the same parameters may provide different classification accuracy depending on the degree of dimorphism in the population under consideration (9).

There is always a need to develop population-specific standards for accurate sex determination based upon the ethnic origin. Hence, measurement standards were developed in many studies for different populations conducted worldwide. The characteristics of skeletal remains differ from one population to another as population-specific osteometric standards were built for sex determination (2,9, 37).

The limitation of this study was that the biological profile of age, sex and ancestry were solely dependent on the data given by the institution. There may be bias on the part of taking history of the deceased person with regards to ancestry, age and sex. The best recourse is to have a direct contact with the relatives to obtain the correct biological profile for each case to increase the accuracy and reliability of the data. For future research, it is suggested that the sample size is increased so that it gives a better representation of the population.

Conclusion

In conclusion, the mandible may exist in different morphological shapes and measurements. These factors may be influenced by various socio-demographical factors, which may contribute to its final appearance. The results of the present study would enhance human identification by the analysis of mandible. Further research may be needed to expand on other related parameters in a larger sample size for validation and comparison purposes.

Appendix

6.1 Equation

Eq(A.1)

P=0.1*BCB+0.641*BGB–0.173*MBH+0.153*SH-0.009*$MAXBR$+0.049*$MINBR$+0.099*$MAXHR$+0.088*CH+0.518*CNH

Eq (A.2)

P=0.723*BGB+0.642*CNH

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