

FORENSIC SEX CLASSIFICATION USING CUT-OFF VALUES FROM CRANIO-MANDIBULAR RADIOLOGIC PARAMETERS

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ABSTRACT

Introduction: In the context of forensic identification, sex determination is the first important step, and the mandible is of particular interest because it shows clear signs of dimorphism.

Objectives: The purpose of this investigation was sex classification through the application of several cranio-mandibular metric variables in a Portuguese adult population.

Material and methods: 206 orthopantomographic images (116 females and 90 males) were selected from Portuguese adults aged between 25 and 79 years. From each image, 14 linear variables were measured using ImageJ® software. IBM SPSS® software version 27.0 was applied to analyze data presented as extremes, mean, standard deviation, and median. Statistical methodologies included intra-class analysis, normality test, *t*-test, Mann-Whitney test, logistic regression, and ROC curve to determine cut-off point and respective sensitivity and specificity of sex classification.

Results: Comparing the two sexes, all variables showed significant differences, except for the angular variables. Variables with the best area under ROC curve were height of the right (0.861) and left (0.850) mandibular ramus. Based on the logistic regression, the left coronoid height, right mandible body height, left mandible body height, and right mandible ramus height showed an accuracy level of 83.0%, sensitivity of 86.2%, and specificity of 78.9% in sex classification.

Conclusions: The obtained results show identifiable mandibular dimorphism in the measurements of mandibular structures in orthopantomography images. These metric variables allow for the creation of discrimination models between males and females in a Portuguese adult population.

Key words: forensic odontology, sex classification, orthopantomography, mandibular parameters.

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INTRODUCTION

During the reconstructive phase of skeletonized cadavers or identification of a person from catastrophic events, the first important step is sex determination. Cranio-mandibular structures have dense bone tissue in their constitution, one of the characteristics that makes them more resistant to damages and putrefaction processes [1-14]. The mandible is of particular interest in the process of sex determination because it shows clear

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signs of dimorphism [3, 4, 14]. Mandibular dimorphism is affected by the size and shape of masticatory muscles, considering that masticatory bite forces in males and females have different frequency and consequently, male bones are generally larger and stronger than female bones [4].

Age, sex, ethnic group, and type of occlusion affect morphological characteristics of the mandible. Scientific evidences demonstrate that aging process is accompanied by re-modeling of the mandibular bone [1, 5, 6, 9, 14].

The main marks of dimorphism in the mandible after adolescence age include general size as well as chin shape and mandible angle; however, the objective and accurate interpretation of these morphological indicators are difficult, showing substantial inter- and intra-observer differences [6, 13].

Up till date, several studies have focused on radiographic osteometry as an applicable tool for sex and height estimations in forensic identifications, without mechanical intervention or maceration [1-5, 7, 8, 13, 14].

Radiographic imagining is essential tool in forensic dentistry. Therefore, orthopantomography is the most widely used method as extra-oral radiography, with its benefits including wide coverage of structures, low cost, and ease of obtaining. It is an excellent choice for the examination of many structures [4, 7].

Recently, several studies were carried out on the ability to estimate the generic sex factor based on radiographs in different populations [1-4, 6, 8-10, 12, 13].

OBJECTIVES

The purpose of this investigation was sex classification through the application of several cranio-mandibular metric variables in a Portuguese adult population.

MATERIAL AND METHODS

The present study was performed in accordance with the ethical standards laid down by Faculty of Dental Medicine, University of Lisbon Health Ethics Committee, with the approval number of 202121.

SAMPLE

Final sample consisted of 206 orthopantomographic images (116 females and 90 males) from individuals older than 25 years, and of Portuguese origin. Exclusion criteria of dental parameters were at least one missing tooth in each quadrant, presence of bone lesions and/or bone fractures, presence of mandibular deformations and any temporomandibular anomalies. In radiographic parameters, exclusion criteria were distortion on the radiograph that prevented interpretation and presence of positioning errors. Collected data contained the process number, date of birth, sex, and date of orthopantomography images.

MEASUREMENTS

In each orthopantomography image, 14 linear variables, shown in Table 1, were measured. X-ray images in JPG format were analyzed using ImageJ® software program, in which measurements were changed from pixels to millimeters (Figure 1).

STATISTICAL ANALYSIS

Intra-class correlation coefficient (ICC) was applied to quantify intra-observer agreement of the measure-

TABLE 1. List of measurements

CoH_D	Right coronoid height (distance between the coronion point and the inferior wall of the jaw on the right side)
CoH_E	Left coronoid height (distance between the coronion point and the inferior wall of the mandible on the left side)
D1_D	Body height of the right mandible (distance from the alveolar process to the inferior wall of the right mandible)
D1_E	Body height of the left mandible (distance from the alveolar process to the inferior wall of the mandible on the left side)
D2	Height of the chin (distance between the chin and the alveolar crest)
D3_D	Height of the right mandibular ramus (distance between the highest point and the lowest point of the right mandibular ramus)
D3_E	Height of the left mandibular ramus (distance between the highest point and the lowest point of the left mandibular ramus)
MiRB_D	Minimum width of the ramus of the right mandible (smallest antero-posterior width of the ramus of the mandible on the right side)
MiRB_E	Minimum width of the ramus of the left mandible (smallest antero-posterior width of the ramus of the mandible on the left side)
go–go	Distance between gonion on both sides (distance between the right gonion point and the left gonion point)
cdl–cdl	Inter-condylar distance (distance between the most lateral points of both condyles)
co-co	Inter-coronoid distance (distance between the innermost points of the right and left coronoid process)
Agn-go_D	Right gonial angle (angle formed by the line tangent to the lowest point of the right gonial angle and the inferior border of the body of the mandible, and the line tangent to the posterior border of the ramus and the right condyle)
Agn-go_E	Left gonial angle (angle formed by the line tangent to the lowest point of the left gonial angle and the inferior border of the body of the mandible, and the line tangent to the posterior border of the ramus and the left condyle)

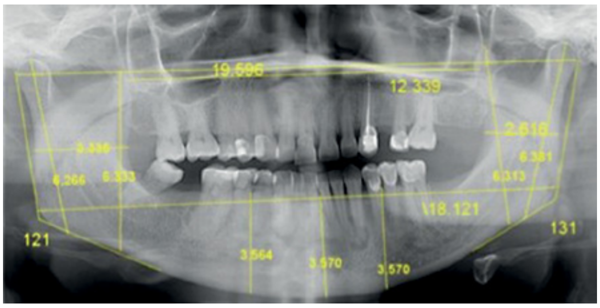

FIGURE 1. Example of applied measurements using ImageJ® software program

TABLE 2. Intra-class correlation coefficients of intra-observer agreement

Variables	CCI
Right coronoid height	0.779
Left coronoid height	0.717
Right mandible height	0.906
Left mandible height	0.847
Chin height	0.836
Right mandible branch height	0.941
Left mandible branch height	0.945
Minimum width right mandible branch	0.812
Minimum width left mandible branch	0.817
Gonion distance	0.773
Inter-condylar distance	0.675
Inter-coronoid distance	0.766
Right gonial angle	0.899
Left gonial angle	0.742

ments. For this purpose, 10% of orthopantomography images were randomly selected. These images were scored again 3 months after the initial process in order to eliminate the memory effect. Additionally, data from the first measurements were hidden during the second measurements, and the agreement of these independent measurements was computed for intra-observer agreement analyses.

To verify normality of data, Kolmogorov-Smirnov normality test was used. To assess the existence of differences between two sexes, *t*-test was applied to all variables (parametric test that requires normality of variables) as well as Mann-Whitney non-parametric test.

Sex classification was performed using each variable and combining several variables through logistic regression. Accuracy, sensitivity, and specificity of the obtained sex classification were evaluated. Finally, receiver operating characteristic (ROC) curves were acquired, and areas under ROC curves (AUC) were computed. In order to perform hypotheses tests, a significance level of 5% was applied. Statistical analysis of the data was performed with IBM SPSS® software version 27.0. The program was used to create a datasheet, manipulate, verify, and analyze the data.

RESULTS

The study sample consisted of 206 orthopantomography images from Portuguese population, 116 (56.3%) of which were females and 90 (43.7%) males. The age range was between 25 and 79 years, with the greater frequency representation of the age group between 35 and 40 years. For each variable, ICC values were recorded, and shown in Table 2. In 11 variables, ICC values were above 0.75, indicating excellent reproducibility, and in 2 variables, ICC values were slightly below 0.75, defining the reproducibility as good [15].

To verify the normality of data, Kolmogorov-Smirnov normality test was applied, and it was found that the vast majority of variables were (approximately) characterized by normal distribution, being reliable application of parametric tests, in particular, *t*-test, for differences in the mean of independent samples. Moreover, in all cases, conclusions in the performance of the non-parametric Mann-Whitney test were the same. Therefore, it was determined that there were significant differences for almost all variables, except for the angular variables (Agn-go_D, Agn-go_E). Considering female sex as the positive state, values for sensitivity, specificity, accuracy, area under ROC curve (AUC), and best cut-off point (to maximize the accuracy) for each variable are presented in Table 3. The representation of various ROC curves is shown in Figure 2. Variables, such as the right gonial angle and the left gonial angle were not reflected in this stage of statistical analysis since they did not allow for a proper classification by sex (no significant differences were detected between the two sexes).

Variables with the best area under ROC curve were the height of the right (0.861) and left (0.850) mandibular ramus. The AUC values can vary between 0 and 1. Values greater than 0.5 indicated that the variables allowed for better classification than a random classification. The higher the AUC value, the more reliable the classification procedure. Logistic regression model using all variables in sex classification was also applied. The regression made it possible to select four variables with statistical significance by applying the backward step-wise procedure, which made it possible to improve the reliability of the sex classification.

Based on the data, using the above-mentioned variables, the probability of male can be obtained from the following equation:

$$\frac{p_M}{1 - p_M} = e^{-29.966 + 0.789LCH - 3.666BHRM + 4.639BHLM + 3.222HRRM}$$

TABLE 3. Values for sensitivity, specificity, accuracy, area under ROC curve (AUC), and cut-off point per variable

Variable	Sensitivity	Specificity	Accuracy	AUC	Cut-off point
Right coronoid height	81.9	57.8	71.4	0.780	6.34
Left coronoid height	80.2	58.9	70.9	0.786	6.30
Right mandible height	77.6	55.6	68.0	0.734	3.25
Left mandible height	74.1	58.9	67.5	0.757	3.25
Chin height	75.0	57.8	67.5	0.747	3.33
Right mandible branch height	85.3	71.1	79.1	0.861	6.80
Left mandible branch height	85.3	72.2	79.6	0.850	6.81
Minimum width right mandible branch	80.2	31.1	58.7	0.617	2.88
Minimum width left mandible branch	85.3	33.3	62.6	0.654	2.80
Gonion distance both sides	76.7	36.7	59.2	0.684	16.87
Inter-condylar distance	81.9	34.4	61.2	0.647	18.45
Inter-coronoid distance	75.0	28.9	54.9	0.608	11.41

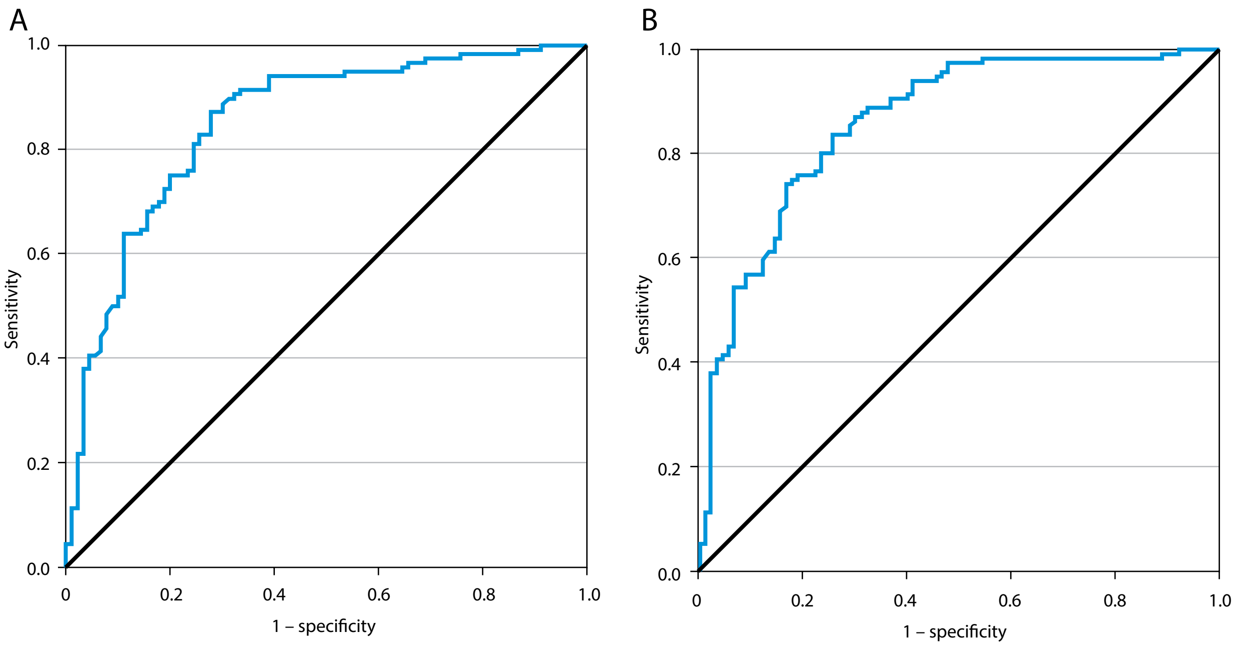

FIGURE 2. ROC curves for the height of the right (**A**) and left (**B**) mandibular ramus

where p_M is the probability of being male, *LCH* is the left coronoid height, *BHRM* is the body height of the right mandible, *BHLM* is the body height of the left mandible, and *HRRM* is the height of the ramus of the right mandible.

Based on the derived formula, the probability of each male can be estimated, and therefore the sex classification can be obtained with a cut-off point of 0.5 (if the estimated probability was greater than 0.5, the individual was classified as male, otherwise as female).

Table 4 shows values of accuracy of 83.0, sensitivity of 86.2, and specificity of 78.9, and the area under ROC curve was 0.887 (Figure 3). These values indicated that the sex classification was more reliable than using the best variables individually. Based on male probabilities estimates obtained for all the individuals in the sample, the histogram of probabilities by sex is

TABLE 4. Logistic regression with all variables. Classification table using a cut-off point of 0.5

	Sex classification		Correct percentage
	Female	Male	
Real sex			
Female	100	16	86.2
Male	19	71	78.9
Global percentage			83.0

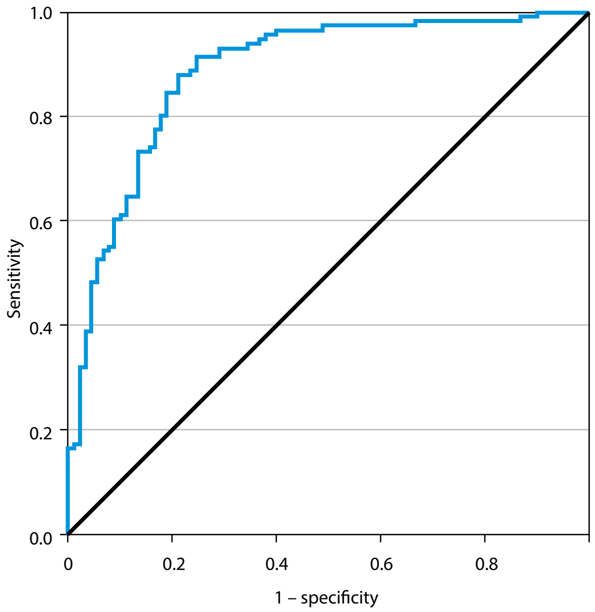

FIGURE 3. ROC curve for four variables obtained from logistic regression model

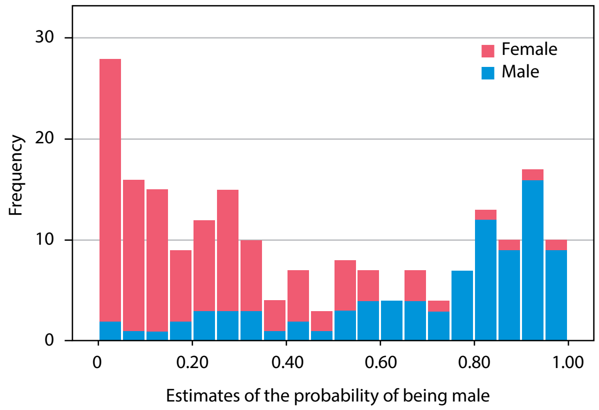

FIGURE 4. Histogram of male probabilities estimates by sex

shown in Figure 4. According to this graph, an ambiguous classification could be defined in values, in which there was a significant number of individuals of both sexes, e.g., classifying as follows: Female: p_M up to 0.35; Ambiguous: p_M between 0.35 and 0.7; Male: p_M greater than 0.7.

Therefore, despite the existence of a group of individuals, who were not classified (about 19.4 percent of the sample), the reliability of the classification increased, with the accuracy level of 88.0, sensitivity of 94.7, and specificity of 78.9. Therefore, the greater the distance of the estimated probability by the logistic regression from the value 0.5 (equal probability associated with both the sexes), the greater the reliability of the classification.

DISCUSSION

Orthopantomography as a radiograph image capture method have some limitations, including magnification and geometric distortion, alteration between the vertical dimension in contrast with the horizontal dimension, being therefore a very sensitive technique to positioning errors [2, 3]. A study based on measurements of structures through orthopantomography may involve some interference in the data obtained due to the probability of the above limitations. Considering these probabilities, the applied statistical analysis seeks to minimize these possible effects.

Moreover, other studies have demonstrated that vertical measurements in orthopantomography, when performed with measurement tools calibrated by programs, present acceptable accuracy and reproducibility. This is considered an advantage, when the mandible is modified by diagenetic processes and is fragile to perform measurements directly in the bone [1-4, 6, 8-10, 12, 13].

The CCI values obtained from the comparison of measurement times for 11 variables were above 0.75, indicating excellent reproducibility, and in 3 variables, the CCI values were slightly below 0.75, defining reproducibility as good [8]. These results are in line with similar literature: Farzaneh *et al.* [1] reported 0.92 for intra-observer reproducibility, and Damera *et al.* [4] a value of 0.81 [1, 4].

All the variables showed significant differences between the sexes ($p < 0.001$), except for the angular variables (Agn-go_D, Agn-go_E) with p-values > 0.05. P-values < 0.001 agree with comparable studies: Sairam *et al.* (2016) referred p-values < 0.001, Farzaneh *et al.* [1] $p < 0.0001$, Abu-Taleb *et al.* [10] $p < 0.001$, Damera *et al.* [4] $p = 0.00$, Indira *et al.* [3] $p < 0.001$, Sambhana *et al.* [11] $p < 0.0001$, and Al-Shamout *et al.* [13] $p < 0.0001$. However, for angular measurements with p-values > 0.05, some comparable studies reported different results: Farzaneh *et al.* [1] $p < 0.0001$, Abu-Taleb *et al.* [10] $p < 0.001$, Damera *et al.* [4] $p = 0.00$, and Chole *et al.* [12] $p < 0.05$. For the same angular variables, other studies obtained p-values > 0.05, such as Sambhana *et al.* [11] with $p = 0.097$ and Al-Shamout *et al.* [13] with $p = 0.955$.

It is important to mention that the combination of variables studied in the literature present, for the most part, differences in relation to those analyzed in the current study. A study of Farzaneh *et al.* [1] showed the same variables [1].

Four variables with statistical significance that allow to improve the reliability of the sex classification were chosen through logistic regression, and included the left coronoid height, the height of the body of the right mandible, the height of the body of the left mandible, and the height of the ramus of the right mandible. Based on these variables, an accuracy level of 83% was achieved in the sex classification.

Sairam *et al.* [2] used five variables of the mandibular branch, and showed an accuracy of 79.5% on the right side and 77% on the left side.

In a study by Farzaneh *et al.* [1], four variables with greater reliability in the classification were chosen, including the height of the right mandibular ramus, the height of the chin, the inter-condylar distance, and the right coronoid height. Based on these variables, they obtained an accuracy level of 82.5%.

Abu-Taleb *et al.* [10] identified the height of the mandibular ramus as the only variable with significant reliability in the classification by sex. Based on this variable, they obtained 81% of correct classifications in the female group and 77.9% of correct classifications in the male group, with an overall correct classification of 79.6%.

In Damera *et al.* study [4], variables with significant predictive values were the height of mandibular ramus, the projection of mandibular ramus, the coronoid height, the gonial angle, the distance between gonions on both sides, the maximum width of mandibular ramus, and the minimum width of the ramus of mandible. Based on these variables, classification accuracy was determined as 83.8%.

In a study by Indira *et al.* [3], the identified predictive variables included the minimum width of mandibular ramus, the coronoid height, and the projection of mandibular ramus. According to these variables, the overall correct classification was obtained as 76%. In Sambhana *et al.* study [11], the coronoid height, the mandibular body height, the mandibular ramus height, the minimum mandibular ramus width, the maximum mandibular ramus width, and the mandibular length were identified as having the greatest classification reliability. The authors reported an overall accuracy level of 75.8%.

All of the above-mentioned studies show the variable height of the mandibular ramus as one of the significant indicators, or even the only significant indicator in the sex classification.

A systematic review carried out in 2020 by Hazari *et al.* [14] that included publications of the last 15 years on the sexual dimorphism of the mandible, concluded that 87.5% of the studies carried out with orthopantomography images showed significant statistical results indicating the possibility of using adult mandible in the identification of both sexes and population affinity.

CONCLUSIONS

The results of the current study demonstrate identifiable mandibular dimorphism in the measurements of mandibular structures in orthopantomography images. Moreover, they suggest that sexual determination based on cranio-mandibular radiological parameters is possible, and may be a useful tool in the reconstructive phase of cadaver identification, when direct measurements are difficult or impossible.

In the selected sample, the left coronoid height, the right mandibular body height, the left mandibular body height, and the right mandibular ramus height demonstrated high sexual dimorphism, and proved to be beneficial in the sex classification. These metric variables allowed for the creation of estimation models, with discrimination between males and females of the studied population.

CONFLICT OF INTERESTS

The authors have no competing interests to declare that are relevant to the content of this article.

ETHICAL STATEMENT

This study was approved by the Ethics Committee of Health from Faculdade de Medicina Dentária da Universidade de Lisboa. The study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and comparable standards.

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CONFLICT OF INTERESTS

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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