SEXUAL DIMORPHISM IN THE MANDIBLE IN A PORTUGESE POPULATION – PREDICTING THE GENDER FOR FORENSIC PURPOSE: A PILOT STUDY

Dimorfismo sexual mandibular da população Portuguesa – Predição do gênero para análise forense: Um estudo piloto

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RESUMO

Este estudo teve como objetivo avaliar o dimorfismo sexual em uma coleção de mandíbulas portuguesas através de uma metodologia métrica digital, utilizando análise estatística descritiva, inferencial e multivariada para identificar quais parâmetros são mais dimórficos e quais são os melhores preditores de sexo. Trinta e três mandíbulas (14 mulheres e 19 homens) e pertences pessoais foram fotograficamente registrados com código e sexo. Os dados foram coletados por tomografia e as medidas foram feitas pelo software Simplant Pro. Foram registrados a largura máxima e mínima do ramo mandibular, altura condilar, altura do processo coronoide, altura da sínfise mandibular, ângulo mandibular, distâncias bimentual, biantegonial, bigonial e bicondilar e comprimento máximo mandibular. A análise estatística foi realizada utilizando IBM® SPSS. Os resultados mostraram diferenças estatisticamente significativas para os seguintes parâmetros: altura do processo coronoide, altura do côndilo, comprimento máximo da mandíbula e largura mínima do ramo mandibular. Na análise estatística multivariada foi possível identificar a altura do processo coronoide como melhor preditor de sexo com precisão em 72,2% dos casos. Isto permite uma diferenciação mais fácil entre mandíbulas femininas e masculinas com uma precisão de 64,3% e 78,9%, respectivamente. Foi possível concluir que a altura do processo coronoide é o parâmetro mais dimórfico e o melhor preditor de sexo na amostra.

Palavras-chave: Mandíbula; Dimorfismo sexual; Tomografia Computadorizada de Feixe Cônico; Perfil biológico; Diagnóstico forense.

ABSTRACT

This study aimed to assess sex dimorphism in a collection of Portuguese mandibles through a digital metric methodology by using descriptive, inferential, and multivariate statistical analysis to identify which parameters are the most dimorphic and which are the best sex predictors. Thirty-three mandibles (14 females and 19 males) and personal belongings were photographically registered with code and sex. Data was collected using tomography, and measurements were made using the Simplant Pro software. The maximum and minimum width of the mandibular ramus, condylar height, coronoid process height, mandibular symphysis height, mandibular angle, bi-mental, bi-antegonial, bi-gonial and bi-condylar distances, and maximal mandibular length were registered. Statistical analysis was performed using *IBM® SPSS*. The results showed statistically significant differences for the following parameters: coronoid process height, condyle height, the maximum length of the mandible, and the minimum width of the mandibular ramus. In the multivariate statistical analysis, it was possible to identify the coronoid process height as the best sex predictor accurately in 72.2% of cases. This allows for easier differentiation between female and male mandibles with an accuracy of 64.3% and 78.9%, respectively. It was possible to conclude that the coronoid process height is the most dimorphic parameter and the best sex predictor in the sample.

Keywords: Mandible; Sex dimorphism; Cone Beam Computer Tomography; Biological profile; Forensic diagnosis.

INTRODUCTION

The world witnesses' multiple circumstances, such as natural disasters, conflicts, and crimes, and it is essential to use identification methodologies based on morphological and dental knowledge (FRANKLIN et al., 2006; ALVES, 2012). Forensic Dentistry has a fundamental role in human identification in multiple situations of medicolegal practice (ALVES, 2012). Morphological analysis of dental pieces and anatomical structures of the maxillofacial complex is considered one of the most reliable identification methods (WADHWAN et al., 2014).

The identification process is based on the individual's biological profile, in which sex diagnosis is a fundamental step, specifically for each population group (ISCAN, 2005; FRANKLIN et al., 2006; FRANKLIN et al., 2008; WADHWAN et al., 2014). It depends on the post-mortem conservation of dimorphic elements (ISCAN, 2005; WHITE, 2005). The mandible is the lowest structure of the skull. It is a mobile, U-shaped bone that does not present a bone articulation (WHITE, 2005; ALIAS et al., 2018). The complex shape of the human mandible exhibits a series of curvatures, with a significant variation between individuals in terms of morphology and dimension (WHITE, 2005; ALIAS et al., 2018). Several studies demonstrated the presence of mandibular sex dimorphism (SAINI et al., 2011; CAPPELLA et al., 2020). Male mandibles are larger and denser, with greater body height, larger condyles, more quadrangular chins, closer gonial angles, more prominent mental eminences, and muscular insertion zones more wrinkled than females (WHITE, 2005; ALVES, 2012).

Some authors have shown the importance of sex identification through mandibular bone morphological analysis (ISCAN, 2005; ELIASOVA et al., 2021). Sex diagnosis can be performed through visual analysis of bone morphology - non-metric method or mathematical and statistical measurements and analysis-metric methods (GALDAMES & SMITH, 2008). Metric methods are the most used because they are more accurate and less susceptible to error (ISCAN, 2005; CAPPELLA et al., 2020). Traditionally, mandibular measures were taken directly on the bone; however, technological progress has increased the utilization of three-dimensional (3D) methods (GARVIN & STOCK, 2016). Cranial measurements in 3D reconstructions are quantitatively accurate (CORTE-REAL et al., 2020). Cone beam computed tomography (CBCT) creates 3D images of good quality and low radiation dose, allowing, with the aid of appropriate software, the precise location and description of bone structures (BUIKSTRA, 1994). CBCT is applied in several medical areas as it allows the 3D visualization of the bones, dentition, the maxillofacial skeleton, and the relationship between anatomical structures (NASSEH & AL-RAWI, 2018). The use of CBCT can be advantageous in the sex identification process (DONG et al., 2015).

Thus, this study aimed to analyze the sexual dimorphism of a mandible collection belonging to the Portuguese National Institute of Legal Medicine and Forensic Sciences - IP (INMLCF - IP), using 3D technology to collect information. Moreover, it is also intended to determine which parameters are more dimorphic and the best for sex predictors.

MATERIALS AND METHODS

This observational, cross-sectional study was conducted after ethics clearance (CE 28/2020). The mandibles of the known sex belonged to a collection of INMLCF - IP.

Eligibility criteria

This study considered the mandibles’ left side as the reference side (BUIKSTRA, 1994). The inclusion criteria were (1) mandibles from people of Portuguese nationality, with age above 18 years; (2) absence of mandibular deformation or pathological anomaly; and (3) absence of post-mortem changes that could compromise the analysis. The exclusion criteria were (1) only mandibular fragments present and (2) a poor conservation state.

3-Dimensional (3D) metric analysis

Considering the conservation state of the sample and following several authors (SAINI et al., 2011; DONG et al., 201; ALIAS et al., 2018), eleven measurement parameters were selected (Table 1 and Figure 1). A numerical code was assigned for each mandible included and letters, from A to K, were assigned to parameters under analysis.

Table 1. Measurement parameters assessed and their respective description.

Parameters	Description
A. Maximum width of mandibular ramus	Distance between the most anterior point of the mandibular ramus and the line connecting the most posterior point of the condyle and the angle of the mandible
B. Minimum width of mandibular ramus	Smallest anterior-posterior diameter of the ramus
C. Condylar height or maximum height of the mandibular ramus	Height of the ramus of the mandible from the most superior point of the condyle to the tubercle or to the most protruding portion of the inferior border of the ramus
D. Coronoid process height	Distance between the uppermost point of the coronoid process and the lower edge of the mandible
E. Mandibular symphysis height	Distance between the alveolar process and the lower edge of the mandible, perpendicular to the base at the level of the mental symphysis
F. Angle of mandibular ramus	Angle formed between the posterior edge of the mandibular ramus and the lower edge of the mandible body
G. Bimentonial distance	Distance between mental holes
H. Biantegonial distance	Distance between the left and right antegonial chamfers
I. Bigonial distance	Distance between left and right gonions
J. Bicondylar distance	Distance between the most lateral points of the left and right condyles
K. Maximum mandibular length	Distance between the mental tubercle to the most posterosuperior point of the condyle

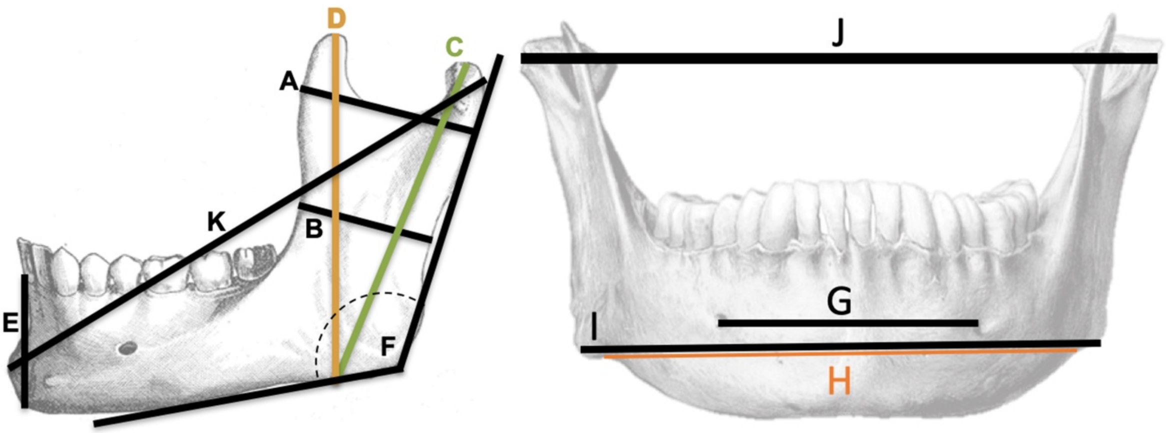

Figure 1. Representative scheme of measurements. A. Maximum width of the mandibular ramus; B. Minimum width of the mandibular ramus; C. Condylar height; D. Coronoid process height; E. Mandibular symphysis height; F. Angle of Mandibular Branch; G. Bimentonial distance; H.

Biantegonial Distance; I. Bigonial Distance; J. Bicondylar distance; K. Maximum mandibular length.

Data collection

The data was obtained through the cone beam computed tomography (CBCT), Planmeca ProMax® 3DMid (90 kV, total filtration 2.5mm Al + 0.5mm Cu), and measurements were taken from the 3D image files generated by the equipment. Each mandible was placed on the equipment for image collection, with temporary fixation. Digital Imaging and Communications in Medicine (DICOM) files were obtained from Simplant Pro software (v. 17.01) using the commands: “Measure Distance” and “Measure Angle”. Measurements were recorded in a spreadsheet within the Microsoft Excel software (v. 16.81, Microsoft Office).

Statistical analysis

All measurements were taken three times, on different days (intervals of 1 week between them), without knowledge of the previous result. The average value was used for the final analysis. A descriptive and inferential statistical analysis methods were performed using the IBM Statistical Package for the Social Sciences (SPSS) (v. 26, IBM, SPSS). The statistical normality of the variables was verified using the Kolmogorov-Smirnov test. For parameters with a normal distribution, the t-student parametric test was performed. For others, the non-parametric Mann-Whitney test was applied. A discriminant function analysis was performed to identify which parameter(s) was(were) the best for predicting the mandible sex. The discriminant function equation was created in two ways: using the combination analysis of all measurement parameters (Direct Multivariate Analysis) and incorporating the parameters that best discriminate sexes (Stepwise Multivariate Analysis).

RESULTS

A total of 44 mandibles were evaluated. After the assessment, 11 were removed; 33 mandibles, which belonged to the known sex (14 females and 19 males), were enrolled. In this sample, two mandibles had the right condyle partially destroyed, and one mandible had the lower edge of the mandibular body on the right side deformed. In these cases, bilateral parameters were not applied. A descriptive statistical analysis for each parameter is reported in Table 2. Except for parameters F and J, the other parameters presented higher mean values in males.

Table 2. Descriptive statistics of parameters for females and males. It was considered information for each parameter, including gender, number involved, mean and standard deviation, minimum (mm) and maximum (mm) obtained for each parameter analyzed.

Parameters (Fig.1)	Gender	*n*	Mean (mm)	Standard Deviation	Minimum (mm)	Maximum (mm)
A.	Female	14	36.90	1.12	31.40	46.38
	Male	19	38.93	0.43	34.80	43.30
B.	Female	14	30.03	1.14	25.11	40.54
	Male	19	31.50	0.46	27.26	34.48
C.	Female	14	62.53	1.29	53.14	70.96
	Male	19	67.27	0.88	61.92	73.28
D.	Female	14	59.09	1.21	52.97	68.85
	Male	19	64.24	1.03	56.09	73.05
E.	Female	14	25.98	1.29	16.04	34.75
	Male	19	28.92	0.86	21.39	34.88
F.	Female	14	128.68	1.84	117.73	142.44
	Male	19	125.33	1.22	115.87	135.73
G.	Female	14	44.18	1.02	35.93	51.72
	Male	19	45.18	0.48	42.02	49.36
H.	Female	14	81.04	1.65	69.16	88.95
	Male	19	81.89	0.96	75.87	92.57
I.	Female	14	88.79	1.97	74.73	99.68
	Male	19	91.48	1.31	82.34	108.36
J.	Female	14	114.67	2.03	101.94	124.49
	Male	19	114.52	1.05	108.30	121.98
K.	Female	14	113.62	1.73	101.65	127.22
	Male	19	118.82	1.16	111.06	126.30

Legend: *Parameters:* A. Maximum width of the mandibular ramus; B. Minimum width of the mandibular ramus; C. Condylar height; D. Coronoid process height; E. Mandibular symphysis height; F. Angle of Mandibular Branch; G. Bimentonial distance; H. Biantegonial Distance; I. Bigonial Distance; J. Bicondylar distance; K. Maximum mandibular length

The only parameter that did not follow the normal distribution was the (B) Minimum Width of the Mandibular Ramus. The non-parametric Mann-Whitney test was used for this parameter and demonstrated a statistically significant difference (p=0.045) between females and males. For the other parameters, the statistical analysis showed there were significant differences in mean values between females and males for (C) Condylar height, (D) Coronoid Process Height, and (K) Biantegonial Distance (p<0.05). Even though there was no statistically significant difference for the parameter (E) Mandibular Symphysis Height, there was a trend toward significance (p=0.058) (Table 3).

Table 3. Statistical analysis comparing the results between genders, considering each parameter.

Parameters	P-value
A.	0.069 t
B.	0.045 (MW) *
C.	0.004 (t) *
D.	0.003 (t) *
E.	0.058 (t)
F.	0.124 (t)
G.	0.341 (t)
H.	0.641 (t)
I.	0.244 (t)
J.	0.943 (t)
K.	0.014 t*

Legend: * Statistically significant (p<0,05); t: t-student test; MW: Mann-Whitney test.

In the multivariate statistical analysis (Table 4), the values of the standardized and non-standardized coefficients obtained, either by the direct or Stepwise methods, were observed. Values of Eigenvalue and canonical correlation proved that the discriminant function was significant. In the direct analysis, with all parameters included, the identification accuracy was 90% (Pooled). It was possible to correctly classify female mandibles in 83.3% of cases and male mandibles in 94.4% of cases. Stepwise analysis eliminated the least influential parameters for classification, leaving parameter D as the one with the highest value for the function with a classification accuracy of 72.2%. It was possible to correctly identify female mandibles in 64.3% of cases and male in 78.3% of cases. Centroid values were allowed to define whether the result of the function is a female or male mandible.

Table 4. Results of the multivariate statistical analysis.

	Coefficient		Eigenvalue	**Canonical correlation**	***Wilk's Lambda***	**Group Centroid**	**Accuracy (%)**				
							Original				Cross-validation
	Standardized	Unstandardized					**F**	**M**	***Pooled***	**SB.**	
Direct											
A.	-1.665	-0.559	1.443	0.769	0.409	F: 1.421 M: -0.947	83.3	94.4	90.0	-11.1	66.7
B.	1.862	0.597									
C.	-0.943	-0.240									
D.	-0.024	-0.006									
E.	-0.469	-0.110									
F.	0.516	0.086									
G.	0.466	0.160									
H.	0.815	0.173									
I.	-0.260	-0.047									
J.	0.723	0.125									
K.	-0.964	-0.168									
Constant		-0.618									
Stepwise											
D.	1.000	0.232	0.265	0.458	0.791	F: -0.609 M: 0.406	64.3	78.9	72.7	6.2	72.7
Constant		-14.406									

Legend. F: Female; M: Male.

DISCUSSION

The determination of sex diagnosis depends on several factors specific to each population group (FRANKLIN et al., 2006; FRANKLIN et al., 2008; CAPPELLA et al., 2020) and on the post-mortem conservation status of anatomical structures (DONG et al., 2015). In the absence of pelvic bones, several studies have shown that the mandible is an adequate instrument for sex determination. It was described as the most resistant bone of the maxillofacial skeleton, maintaining its shape better than other structures (CAPPELLA et al., 2020).

Several authors have already used 3D image analysis (FRANKLIN et al., 2006; CAPPELLA et al., 2020). According to Eliasova *et al*. (2021), images captured by CBCT provide more information to the professional than 2D images, enabling the examination of structures with difficult access. Dentistry has increasingly used this methodology in diagnosis and treatment planning (DOS SANTOS et al., 2022). In a forensic context, it can become an essential tool for collecting information and identifying individuals once it is available in dental offices (DEANA & ALVES, 2017). For this study, some adaptations were made to allow the use of CBCT, specifically for stabilizing the mandible in the equipment. During the 3D images taken, it was found that time consumption for image capture was short, and digital analysis allowed observation and measurement of anatomical details.

The present study sample consisted of 33 mandibles (14 females and 19 males), with mean values obtained generally higher in males (parameters A to E, G, H, I, and K). These results agree with the literature (FRANKLIN et al., 2008; KHAROSHAH et al., 2010; SAINI et al., 2011; ALVES, 2012; İLGÜY et al., 2014; DONG et al., 2015; CAPPELLA et al., 2020). When analyzing the condylar height (Parameter C), the results from the present study were higher than those obtained by Alves (2012), who also evaluated a Portuguese sample. This may be related to the temporal separation between the samples analyzed, which may reflect the socio-environmental influences such as climate, nutrition, pathologies, and occupation that affect mandibles over time (BEJDOVÁ et al., 2013).

However, the values obtained were higher in females for the parameters (F) angle of the mandibular ramus and (J) bicondylar distance. These findings are also in line with the literature (İLGÜY et al., 2014; DONG et al., 2015; DIREK et al. 2018; CAPPELLA et al., 2020). Kharoshah *et al*. (2010) presented different results. This may be related to specific characteristics, such as the geographic origin of the study sample.

Otherwise, bicondylar distance parameter results obtained in the present study do not agree with several studies that showed higher male values (FRANKLIN et al., 2008; KHAROSHAH et al., 2010; ALVES, 2012; İLGÜY et al., 2014; DONG et al., 2015; CAPPELLA et al., 2020). The differences observed may be related to the sample size in the present study and the conservation state of the sample. Inferential statistical analysis demonstrated that parameters (C) Condylar height, (D) Coronoid process height, (K) Maximum mandibular length, and (B) Minimum width of ramus had the greatest sex dimorphism. These facts are in accordance with the literature (FRANKLIN et al., 2008; KHAROSHAH et al., 2010; SAINI et al., 2011, ALVES, 2012; İLGÜY et al., 2014; DONG et al., 2015; DIREK et al. 2018; CAPPELLA et al., 2020). However, the coronoid process height (D) was the most dimorphic parameter.

Furthermore, even though there were no statistically significant differences for the parameter E, symphysis height, there was a trend toward significance ($p=0.058$). In the existing literature, this parameter was reported as dimorphic (FRANKLIN et al., 2008; DONG et al., 2015; CAPPELLA et al., 2020). The difference observed may be explained by the existence of 13 anterior edentulous mandibles, with consequent resorption in this area and an influence on the results (AVILA-ORTIZ et al., 2014). On the other hand, no statistically significant differences were found for parameters A, G, H, and I, which showed a large discrepancy compared to the existing literature. This fact may be related to population variability (FRANKLIN et al., 2008; KHAROSHAH et al., 2010; İLGÜY et al., 2014; DONG et al., 2015; CAPPELLA et al., 2020).

In analyzing the discriminant function, it was possible to define two discriminant functions (Direct and Stepwise) and identify which parameter was the most dimorphic for the sample under study and the best sex predictor. In the direct analysis, with all parameters included in the function, the identification accuracy was 90%. The stepwise analysis allowed the discarding of all the less influential parameters for the classification, leaving the coronoid process height (D) as the one with the greatest relevance for the function. This parameter (D) was the best predictor of sex, with an accuracy of 72.2%. The student's t-test also identified this parameter as the most dimorphic parameter, and the stepwise analysis strengthened these results, defining it as the most predictive parameter of sex. These results agree with the literature (FRANKLIN et al., 2008; SAINI et al., 2011; ALVES, 2012).

In the study conducted by Alves (2012), the condylar height and the bigonial distance were identified as good sex predictors, along with the coronoid process height, which had 80% accuracy). Although this result partially disagrees with the present study, the coronoid process height was to be dimorphic and the best predictor in both studies carried out in the Portuguese population. Franklin *et al*. (2008) highlighted the parameters D, A, and I as the best sex predictors (81.8% accuracy), whereas Saini *et al*. (2011) considered the parameters D and C (80.2% accuracy).

The variety of results observed between the existing literature and the present study may be related to the singularity of sexual dimorphism for each population group, influenced by several factors. Humphrey *et al*. (1999) identified that the most notable variation between population groups occurs in the height and width parameters of the mandibular ramus, where sexual dimorphism tends to be greater (GALDAMES & SMITH, 2008). Socio-environmental factors such as diet, climate, diseases, occupation, and muscle insertions of the masticatory muscles influence mandibular growth and differ between males and females (WEIJS & HILLEN, 1986; LOTH & HENNEBERG, 1996; ROSAS & BASTIR, 2002; GALDAMES & SMITH, 2008; SAINI et al., 2011). Muscular development is influenced by genetics and sexual hormones that contribute to changes in the facial shape of adults (LOTH & HENNEBERG, 1996; HUMPHREY et al., 1999). It has already been shown that severe malnutrition contributes to the reduction of sexual dimorphism, leading to sex misidentification, particularly in males (GALDAMES & SMITH, 2008). The morphological differences that arise from genetically linked growth and development allow a better classification of sex (LOTH & HENNEBERG, 1996).

As the limitations of the study, it is possible to consider the low number of mandibles included. Moreover, it was evaluated mandible from a Portuguese population, which can have other significant parameters in other ethnical groups. Also, 25% (11 mandibles) were removed due to the current condition of preservation.

CONCLUSION

Within the limitations of this study, mostly related to the size and conservation of the sample, it was possible to verify the presence of mandibular sex dimorphism in four parameters collected through 3D images: coronoid process height, condylar height, maximum mandible length, and minimum mandibular width. It was possible to determine a discriminant function for sex classification using all parameters and determine a discriminant function identifying the Coronoid Process Height as the most dimorphic parameter in the sample and the best predictor of sex. Therefore, additional research is needed, using the same parameters and methodology in a more contemporary, extensive, and well-preserved sample representative of the Portuguese population, to confirm the sex dimorphism found in the present study and to corroborate the dimorphic capacity of the Coronoid Process Height so that it can be applied in the forensic context in the future.

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