Research, Society and Development, v. 10, n. 4, e45910414284, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i4.14284

Quantitative analysis of the mandible for sex estimation

Análises quantitativas em mandíbulas para estimativa do sexo

Análisis cuantitativo de mandíbulas para estimar el sexo

Received: 03/25/2021 | Reviewed: 04/03/2021 | Accept: 04/06/2021 | Published: 04/18/2021

Maria Izabel Cardoso Bento
ORCID: https://orcid.org/0000-0002-5900-0385
University of Pernambuco, Brazil
E-mail: cardosobel@outlook.com
Edgard Michel Crosato
ORCID: https://orcid.org/0000-0001-8559-9769
University of São Paulo, Brazil
E-mail: michelcrosato@usp.br
Bianca Marques Santiago
ORCID: https://orcid.org/0000-0001-9559-913X
Federal University of Paraíba, Brazil
E-mail: bianca.santiago@yahoo.com.br
Evelyne Pessoa Soriano
ORCID: https://orcid.org/0000-0001-8337-0194
University of Pernambuco, Brazil
E-mail: evelyne.soriano@upe.br
Marcus Vitor Diniz de Carvalho
ORCID: https://orcid.org/0000-0003-1270-2352
University of Pernambuco, Brazil
E-mail: marcus.carvalho@upe.br
Patrícia Moreira Rabello
ORCID: https://orcid.org/0000-0001-5433-6982
Federal University of Paraíba, Brazil
E-mail: patriciamoreirarabello@gmail.com
Luiz Francesquini Júnior
ORCID: https://orcid.org/0000-0002-6344-3488
State University of Campinas, Brazil
E-mail: francesq@unicamp.br
Adriana Conrado de Almeida
ORCID: https://orcid.org/0000-0001-6141-0458
University of Pernambuco, Brazil
E-mail: aconradoalmeida@yahoo.com.br
Reginaldo Inojosa Carneiro Campello
ORCID: https://orcid.org/0000-0001-6947-9329
University of Pernambuco, Brazil
E-mail: reginaldo.campello@upe.br

Abstract

This study aimed to investigate the applicability of mandibular measures for sex estimation in human dry skulls from two Brazilian bone collections. This was a blind diagnostic study with 471 mandibles of 215 females and 256 males. The variables considered were: bigonial-width; bicondylar-width; right/left condylar process width; coronoid width; distance between the mandibular foramina; distance between the mental foramina; distance between the genial spinal foramina and the right/left mandibular foramina; right/left coronoid process height; right and left mandibular ramus height; right/left mandibular thickness; anterior mandibular thickness; maximum width of the right and left mandibular ramus; minimum width of the right and left mandibular ramus; mandibular-length; and the mandibular angle. Discriminant analysis was performed to check for associations concerning sex both for individual and total measurements. The statistical analysis indicated that all variables were found to be significantly associated with sex. When applied to males and females, the *stepwise* method correctly classified 77.50% and 80.20% of the cases, respectively, with a total percentage of agreement of 78.70%. The left mandibular ramus height (74.80%) and the bigonial width (77.60%) were the variables with the highest agreement rates among males and females, respectively. Equations were generated from the discriminant analysis for each variable and a unique formula for the six variables showed the highest preference for sex. All mandibular measures were statistically different between the sexes, suggesting that the mandible plays an important role in forensic anthropology as a source of quantitative information for sex estimation.

Keywords: Forensic Anthropology; Mandible; Sex Determination by Skeleton; Forensic Dentistry.

Resumo

Objetivou-se investigar a aplicabilidade de medidas mandibulares para estimativa do sexo em crânios secos humanos de duas coleções osteológicas brasileiras. Este foi um estudo do tipo diagnóstico, cego, com 471 mandíbulas de 215 mulheres e 256 homens. As variáveis consideradas foram: largura bigonial; largura bicondilar; largura do processo condilar direito/esquerdo; largura do coronóide; distância entre os forames mandibulares; distância entre os forames mentais; distância entre os forames espinhais geniais e os forames mandibulares direito/esquerdo; altura do processo coronóide direito e esquerdo; altura do ramo mandibular direito/esquerdo; espessura mandibular direita/esquerda; espessura mandibular anterior; largura máxima do ramo mandibular direito/esquerdo; largura mínima do ramo mandibular direito/esquerdo; comprimento mandibular; e o ângulo mandibular. A análise discriminante foi realizada para verificar as associações em relação ao sexo, tanto para as medidas individuais quanto para o total. A análise estatística indicou que todas as variáveis apresentaram associação significativa com o sexo. Quando aplicado a homens e mulheres, o método *stepwise* classificou corretamente 77,50% e 80,20% dos casos, respectivamente, com percentual total de concordância de 78,70%. A altura do ramo mandibular esquerdo (74,80%) e a largura bigonial (77,60%) foram as variáveis com maiores taxas de concordância entre homens e mulheres, respectivamente. Equações foram geradas a partir da análise discriminante para cada variável e uma fórmula única para as seis variáveis que apresentaram maior preferência por sexo. Todas as medidas mandibulares foram estatisticamente diferentes entre os sexos, sugerindo que a mandíbula desempenha um papel importante na antropologia forense como fonte de informação quantitativa para estimativa do sexo.

Palavras-chave: Antropologia Forense; Mandíbula; Determinação do Sexo pelo Esqueleto; Odontologia Legal.

Resumen

El presente estudio tuvo como objetivo investigar la aplicabilidad de las medidas mandibulares para la estimación del sexo en cráneos secos humanos de dos colecciones óseas brasileñas. Este fue un estudio diagnóstico ciego con 471 mandíbulas de 215 mujeres y 256 hombres. Las variables consideradas fueron: bigonial-width; ancho bicondilar; ancho de la apófisis condilar derecha/izquierda; ancho de las coronoides; distancia entre los agujeros mandibulares; distancia entre los agujeros mentonianos; distancia entre los agujeros espinales geniales y los agujeros mandibulares derecho/izquierdo; altura de la apófisis coronoides derecha/izquierda; altura de la rama mandibular derecha/izquierda; espesor mandibular derecho/izquierdo; espesor mandibular anterior; ancho máximo de la rama mandibular derecha/izquierda; ancho mínimo de la rama mandibular derecha/izquierda; longitud mandibular; y el ángulo mandibular. Se realizó un análisis discriminante para verificar las asociaciones con respecto al sexo tanto para las mediciones individuales como para las totales. El análisis estadístico indicó que todas las variables se asociaron significativamente con el sexo. Cuando se aplicó a hombres y mujeres, el método escalonado clasificó correctamente el 77,50% y el 80,20% de los casos, respectivamente, con un porcentaje total de acuerdo del 78,70%. La altura de la rama mandibular izquierda (74,80%) y el ancho bigonial (77,60%) fueron las variables con mayores tasas de concordancia entre hombres y mujeres, respectivamente. Se generaron ecuaciones a partir del análisis discriminante para cada variable y una fórmula única para las seis variables que mostraron la mayor preferencia por el sexo. Todas las medidas mandibulares fueron estadísticamente diferentes entre los sexos, lo que sugiere que la mandíbula juega un papel importante en la antropología forense como fuente de información cuantitativa para la estimación del sexo.

Palabras clave: Antropología Forense; Mandíbula; Determinación del Sexo por el Esqueleto; Odontología Forense.

1. Introduction

Forensic anthropology is a branch of physical anthropology that makes use of anatomical knowledge to analyze human remains and, thereby, to establish the identity of unknown bodies (Garehdaghi et al., 2018). The quest for a putative identity is based on three main aspects, namely: a) the biological profile (estimation of sex, ancestry, age, and height, as well as the search for individual features); b) the establishment of the time of death (based on the circumstances and/or conditions under which the body was found); and c) the search for evidence that indicates the cause of death (James, Nordby, Bell, 2003).

While sex estimation is an important procedure in forensic anthropology to establish the identity of a questioned individual, the conditions under which human segments are found may not always be suitable for the application of conventional methods, which reinforces the need for secondary alternatives to accomplish human identification.

In cases where human remains are the only existing evidence, the skull and teeth are the best-preserved structures (Kumar, Lokanadham, 2013). As it is the largest and strongest bone of the skull, the mandible retains its shape more invariably than other structures, which is why it is usually found intact among other remains. Therefore, the mandible provides important information on the individual to whom it belonged. Moreover, it is the bone with the highest degree of sexual dimorphism in the skull, a parameter that plays a major role in forensic anthropology (Tunis et al., 2017).

Herein, we investigated the applicability of mandibular measures for sex estimation in two cataloged skeletal collections from southeastern and northeastern Brazil.

2. Materials and Methods

Materials

This study followed the regulations of research involving human beings and had prior approval of the Research Ethics Committee at the Center for Health Sciences (under protocol 3.430.164). This study had a cross-sectional design for the analysis of factor and effect characteristics at the same period (Rouquayrol; Almeida Filho, 2003). The main advantages of this type of study are the speed and objectivity with which specific aspects of a given population can be analyzed (Pereira, 2008).

No sample size calculation was required since this study included the entire collection of mandibles from both study centers. The skeletons in these laboratories had been cataloged as to sex and age at death, and access to them was granted through an informed consent form signed by both institutions. This was a blind study in which the examiner had no previous information about the mandibles. The study universe consisted of 560 skeletons, and samples that had missing mandibles or malformation, severe anomaly, traumas, or bone pathologies that could compromise their integrity, were excluded.

The final sample size consisted of 471 mandibles, of which 282 were from the Forensic Physical Anthropology Laboratory at Piracicaba Dental School, University of Campinas (FOP/UNICAMP), and 189 from the Center for Studies in Forensic Anthropology, University of Pernambuco (CEAF/FOP/UPE), in southeastern and northeastern Brazil, respectively.

Methods

In our study, the nominal qualitative variable was sex (male and female). This information was obtained from the available databases of both osteological collections.

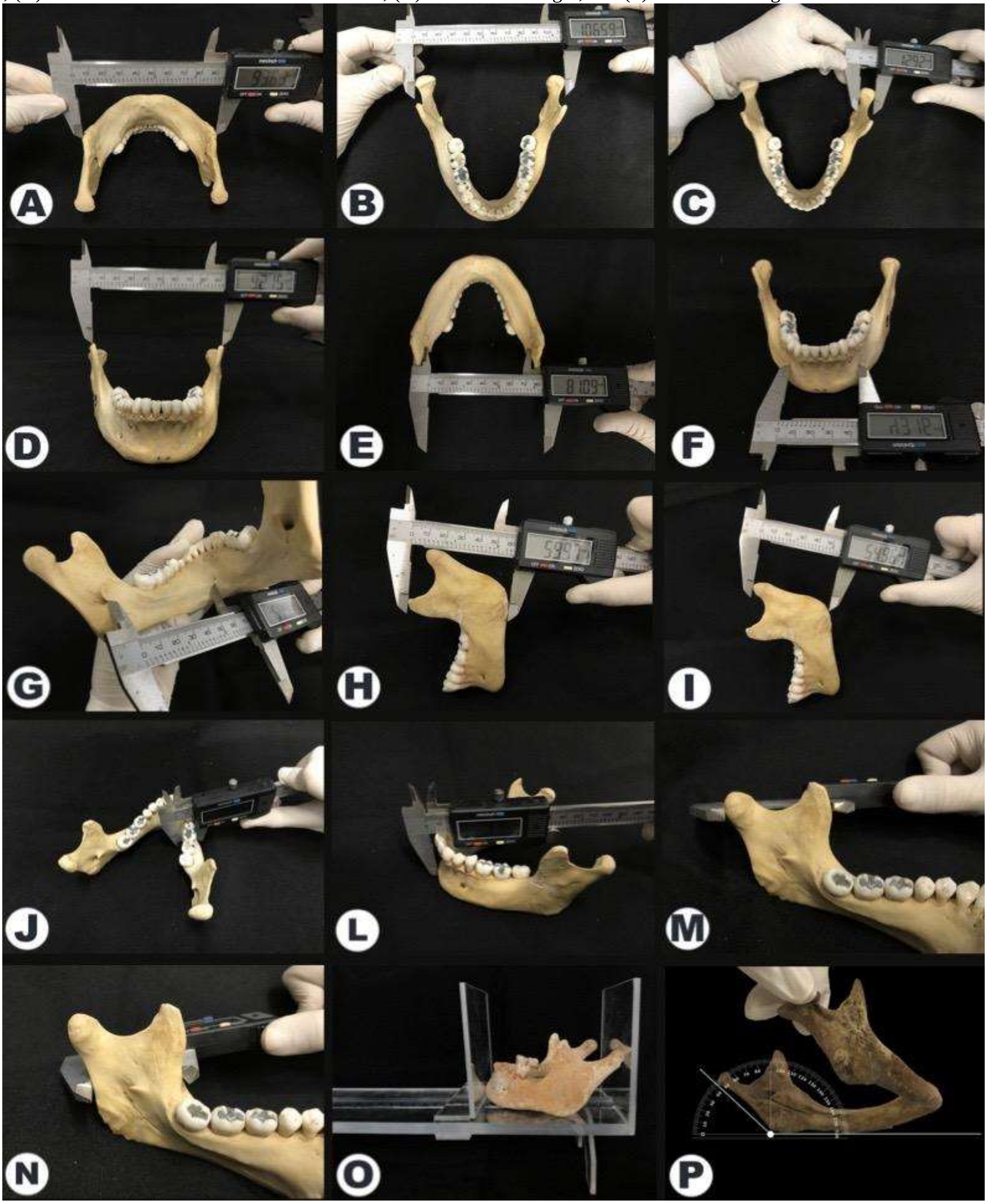
Metric methodologies applied to forensic anthropology provide important guidance for constructing a biological profile of an unidentified individual. As the metric analysis usually makes use of well-defined anatomical points, inter- or intraexaminer errors are potentially reduced when compared to non-metric approaches (Spradley, 2016). Thus, we measured the craniometric points of the mandibles (as described in Table 1 and shown in Figure 1) to standardize the measurements of the entire sample. Quantitative variables were measured using a digital caliper, which was zeroed at the end of each measurement to avoid possible variations that could interfere with the results.

Table 1. Quantitative variables, tools, and definition of the methods.

Quantitative variables	Definition
Tool - Caliper	
Bigonial width	Right gonion (Go) to the left gonion (Go)
Bicondylar width	Right condylion laterale to the left condylion laterale (Cdl)
Right and left condylar process width	Right/left condylion laterale (Cdl) to the right/left condylion mediale (Cdm)
Coronoid width	Right coronion to the left coronion (Co)
Distance between the mandibular foramina	Right mandibular foramen to the left mandibular foramen
Distance between the mental foramina	Right mental foramen to the left mental foramen
Distance between the genial spinal foramina and the right and left mandibular foramina	Right/left mandibular foramen to the center of the genial spinal foramina
Right and left coronoid process height	Right inferior edge of the mandibular ramus to the right/left coronoid (Co)
Right and left mandibular ramus height	Right inferior edge of the mandibular ramus to the right/left condylion superior (Cs)
Right and left mandibular thickness	Right/left mental foramen
Anterior mandibular thickness	Pogonion (pg) to the center of the spinal genial foramina
Maximum width of the right and left mandibular ramus	Most anterior point of the right coronoid process to the most posterior point of the right/left mandibular condyle
Minimum width of the right and left mandibular ramus	Most posterior point of the right coronoid process to the most anterior point of the right mandibular condyle
Tool – Osteometric Table	
Mandibular length	Condyles to the most anterior point of the mandibular body
Tool – Mobile Protractor	
Mandibular angle	Inferior edge of the mandible and the posterior edge of the ramus

Source: Authors.

Figure 1. Protocols for measuring the mandibles to obtain the quantitative data: (A) Bigonial-width; (B) bicondylar-width; (C) condylar process width; (D) coronoid-width; (E) distance between the mandibular foramina; (F) distance between the mental foramina; (G) distance between the genial spinal foramen and the mandibular foramen; (H) coronoid process height; (I) mandibular ramus height; (J) mandibular-thickness; (L) anterior mandibular thickness; (M) maximum width of the mandibular ramus; (N) minimum width of the mandibular ramus; (O) mandibular-length; and (P) mandibular angle.



Source: Professor Eduardo Daruge Forensic Anthropology Laboratory (FOP/Unicamp) and the Center for Studies in Forensic Anthropology (CEAF/FOP/UPE) (2017).

A pilot study was previously performed to calibrate the examiner following the same criteria adopted in the full-length study. Ten mandibles from the CEAF/UPE were randomly selected. To check for intra-examiner agreement, each mandible was examined twice by the same examiner for all quantitative variables, with a seven-day interval between the first and the second measurements.

The Intraclass correlation coefficient showed an optimal agreement between the measurements (≥ 0.94), indicating adequate training of the examiner on the study criteria. As no adjustments were required based on the pilot study, these ten mandibles were also included in the final sample.

Statistical analysis

The data were submitted to statistical analysis in the Statistical Package for the Social Sciences program (SPSS® Professional Statistics, version 22.0). The quantitative data were first checked for normal distribution, and *t*-test or Mann-Whitney test was used for parametric and nonparametric analysis, respectively, with a 5% significance level. A discriminant analysis was carried out to determine sex-matching cases based on each quantitative variable. The *stepwise* method of the discriminant analysis was used to determine the agreement percentage by sex and total sample.

3. Results

Of the 471 mandibles analyzed, 256 (54.40%) were males and 215 (45.60%) were females. Means and standard deviations were calculated for each quantitative variable related to sex. The variables with normal and non-normal data distribution were compared by Student's *t*-test and Mann-Whitney test, respectively (Table 2).

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i4.14284

Table 2. Distribution of the sample according to sex and mandibular quantitative variable.

N= 471	Sex	Mean	SD	P-value
Bigonial-width	Male	97.31	±6.07	p(1)=0.000*
	Female	90.35	±5.35	
Bicondylar-width	Male	119.10	±6.52	p(1)=0.000*
	Female	114.68	±6.38	
Right condylar process width	Male	20.06	±2.12	p(1) =0.000*
	Female	18.51	±2.24	
Left condylar process width	Male	19.80	±2.28	p(1)=0.000*
	Female	18.35	±2.23	
Coronoid-width	Male	96.70	±5.75	p(1)=0.000*
	Female	93.39	±5.41	
Distance between the mandibular foramina	Male	86.16	±4.36	p(1)=0.000*
	Female	81.74	±4.02	
Distance between the mental foramina	Male	43.54	±2.93	p(1)=0.000*
	Female	41.59	±3.09	
Distance between the genial spinal foramen and the right mandibular foramen	Male	73.33	±4.40	p(1)=0.000*
	Female	69.91	±4.01	
Distance between the genial spinal foramen and the left mandibular foramen	Male	73.51	±4.22	p(1)=0.000*
	Female	70.14	±3.93	
Right coronoid process height	Male	62.11	±6.16	p(1)=0.000*
	Female	56.08	±5.66	
Left coronoid process height	Male	61.88	±5.97	p(1)=0.000*
	Female	56.32	±5.41	
Right mandibular ramus height	Male	63.42	±5.08	p(1)=0.000*
	Female	57.32	±5.20	
Left mandibular ramus height	Male	64.11	±5.03	p(1)=0.000*
	Female	57.98	±5.06	
Right mandibular thickness	Male	11.22	±1.65	p(2)=0.001*
	Female	10.73	±1.54	
Left mandibular thickness	Male	11.33	±1.69	p(2)=0.000*
	Female	10.69	±1.54	
Anterior mandibular thickness	Male	14.66	±1.91	p(1)=0.000*
	Female	13.95	±1.81	
Maximum width of the right mandibular ramus	Male	42.07	±3.72	p(1)=0.000*
	Female	40.16	±3.21	
Maximum width of the right mandibular ramus	Male	42.27	±3.63	p(1)=0.000*
	Female	40.24	±3.43	
Minimum width of the right mandibular ramus	Male	30.06	±3.58	p(1)=0.000*
	Female	27.98	±3.24	
Minimum width of the left mandibular ramus	Male	30.13	±3.59	p(1)=0.000*
	Female	28.25	±3.32	
Mandibular-length	Male	110.82	±6.54	p(2)=0.000*
	Female	105.47	±6.17	
Mandibular angle	Male	126.56	±7.71	p(2)=0.000*
	Female	130.18	±6.84	

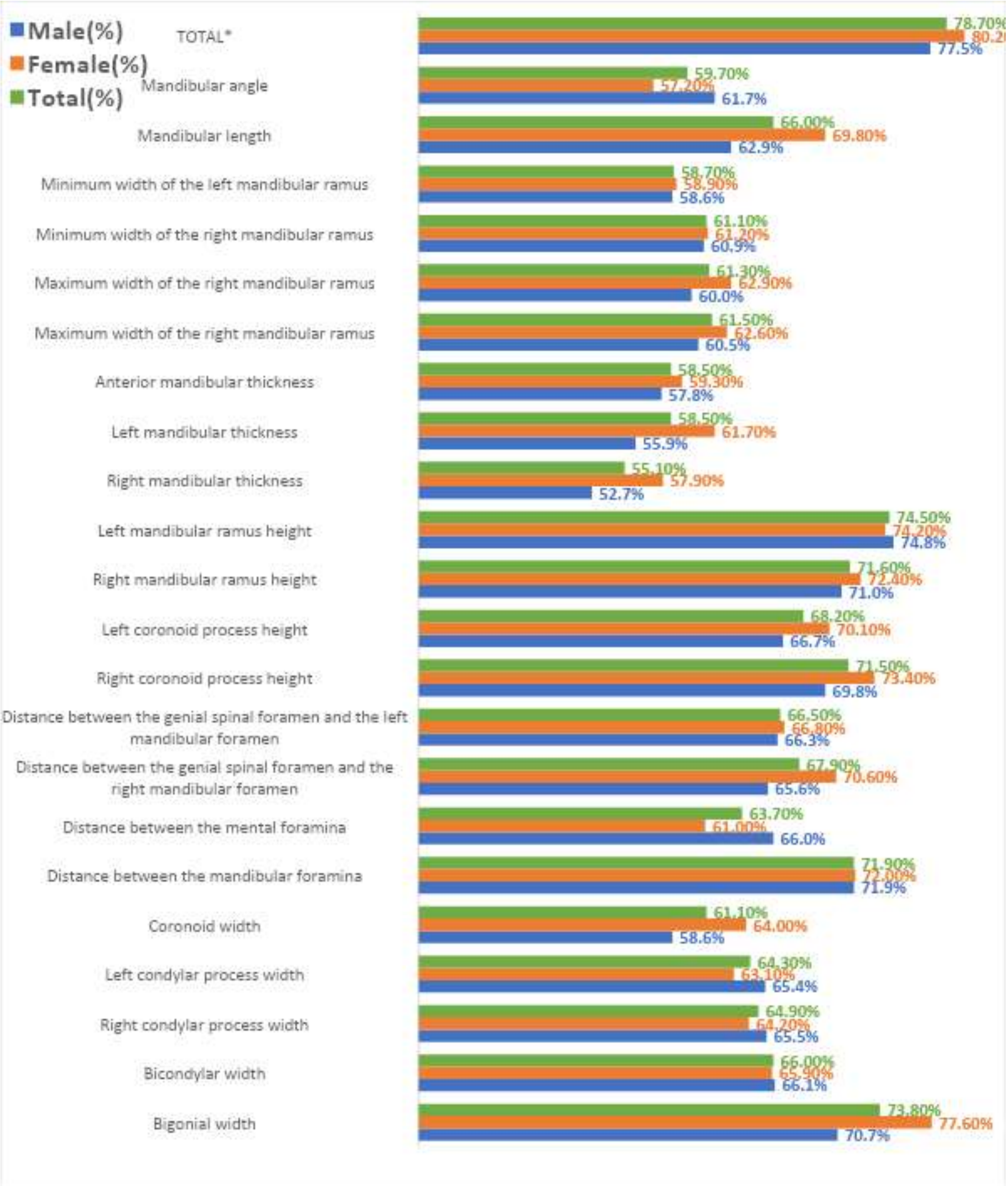
(1) Student's t-test. (2) Mann-Whitney test. (*) Significance level at 5.0%. Source: Authors.

Table 2 shows that all mean measurements in males were significantly higher than those in females (*P*<0.05), indicating that the null hypothesis was rejected, and a statistically significant association was found between all quantitative variables and sex.

The discriminant data analysis indicated sex-related variability of the measurements, which ranged from 52.70% to 74.80% among males and from 57.20% to 77.60% among females (Figure 2).

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i4.14284

Figure 2. Discriminant analysis of mandibular quantitative variables for sex estimation.



Source: Authors.

As shown in Figure 2, the variables that showed the lowest total agreement rates (less than 60.0%) were the anterior, right/left mandibular thickness as well as the minimum width of the left mandibular ramus. These results indicate that although statistically significant differences were observed between these variables and the individual's sex, they failed to yield a good agreement rate and correct total correlations.

While the discriminant function has been accurately used in forensic anthropology, it may be subject to population-specific sensitivity, which reveals a need for generated discriminant equations to be valid and applied individually to each studied population (Lopez-Capp et al., 2018). Therefore, in our study, discriminant equations were obtained for each variable according to sex (Table 3).

Table 3. Discriminant equation of mandibular quantitative variables for sex estimation (SP = Sex Prediction).

Equation for the male sex	Equation for the female sex
SP= -145.135+(Bigonial-width*2.982)	SP= -125.597+(Bigonial-width*2.766)
SP= -171.495+(Bicondylar-width*2.879)	SP= -158.87+(Bicondylar-width* 2.779)
SP= -42.242+(Right condylar process width*4.216)	SP= -35.867+(Right condylar process width*3.885)
SP= -37.496+(Left condylar process width*3.793)	SP= -32.225+(Left condylar process width*3.793)
SP=-149.870+(Coronoid-width*3.099)	SP=-139.870+(Coronoid-width*2.991)
SP=-209.810+(Distance between the mandibular foramina*4.865)	SP=-188.500+(Distance between the mandibular foramina*4.612)
SP=-105.611+(Distance between the mental foramina*4.846)	SP=-96.100+(Distance between the mental foramina*4.622)
SP=-149.782+(Distance between the genial spinal foramen and the right mandibular foramen*4.086)	SP=-139.215+(Distance between the genial spinal foramen and the right mandibular foramen*3.897)
SP=-162.384+(Distance between the genial spinal foramen and the left mandibular foramen*4.417)	SP=-147.746+(Distance between the genial spinal foramen and the left mandibular foramen*4.213)
SP=-55.025+(Right coronoid process height*1.772)	SP=-44.762+(Right coronoid process height*1.599)
SP=-58.064+(Left coronoid process height*1.879)	SP=-48.071+(Left coronoid process height*1.710)
SP=-74.630+(Right mandibular ramus height*2.359)	SP=-61.097+(Right mandibular ramus height*2.134)
SP=-79.313+(Left mandibular ramus height*2.481)	SP=-65.160+(Left mandibular ramus height*2.249)
SP=-24.732+(Right mandibular thickness*4.398)	SP=-22.467+(Right mandibular thickness*4.191)
SP=-24.527+(Left mandibular thickness*4.325)	SP=-21.711+(Left mandibular thickness*4.069)
SP=-31.362+(Anterior mandibular thickness*4.276)	SP=-28.320+(Anterior mandibular thickness*4.063)
SP=-73.484+(Maximum width of the right mandibular ramus*3.494)	SP=-67.022+(Maximum width of the right mandibular ramus*3.337)
SP=-71,747+(Maximum width of the left mandibular ramus*3.396)	SP=-65.097+(Maximum width of the left mandibular ramus*3.235)
SP=-38.374+(Minimum width of the right mandibular ramus*2.554)	SP=-33.228+(Minimum width of the right mandibular ramus*2.376)
SP=-37.777+(Minimum width of the left mandibular ramus*2.510)	SP=-33.215+(Minimum width of the left mandibular ramus*2.353)
SP=-153.381*(Mandibular-length*2.768)	SP=-138.879*(Mandibular-length*2.634)
SP=-147.551*(Mandibular angle*2.326)	SP=-155.515*(Mandibular angle*2.387)

Source: Authors.

As human remains are hardly found undamaged, Table 3 provides a range of equations that were generated for all quantitative variables analyzed herein. This analysis shows the percentage of sex predilection for each measure individually. Moreover, two pooled equations (one for males and another for females) were generated from the six variables that showed the greatest predilection for sex, namely: bigonial-width (73.80%), distance between the mandibular foramina (71.90%), right coronoid process height (71.50%), left coronoid process height (68.20%), right mandibular ramus height (71.60%) and left mandibular ramus height (74.50%) (Table 4).

Table 4. Discriminant analysis of the six most significant mandibular quantitative variables for sex estimation.

Quantitative Variables	Male (%)	Female (%)	Total (%)
Six most significant variables	**77.91%**	**82.55%**	**80.23%**

Equation for the male sex: SP= -253.420+(Bigonial-width*1.214) + (Distance between the mandibular foramina*3.387) + (Right coronoid process height*-0.537) + (Left coronoid process height*0.631) + (Right mandibular ramus height*1.335) + (Left mandibular ramus height*0.102)

Equation for the female sex: SP= -222.428+(Bigonial-width*1.069) + (Distance between the mandibular foramina*3.329) + (Right coronoid process height*-0.575) + (Left coronoid process height*0.649) + (Right mandibular ramus height*1.217) + (Left mandibular ramus height*0.035)

Source: Authors.

When the six measures that showed individually the best percentage of sex predilection were pooled, the method correctly classified the sex in 71.91%, 82.55%, and 80.23% of the males, females, and total sample, respectively.

4. Discussion

The human mandible has a dense layer of compact bone that makes it the strongest structure of the skull. The mandible undergoes growth spurts during adolescence and, more importantly, it is the last skull bone to cease growth, which is a desirable parameter for sex determination (Saini et al., 2011).

The volume and dimensions of the chewing muscles have a direct relationship with the bone structures from where the muscles originate (Azaroual et al., 2014). Throughout the years, males have acquired a stronger musculature (Lopez-Capp et al., 2018) than females; hence, such impressions left onto skeletal structures may justify the high degree of sexual dimorphism in human skulls, as previously described in other studies using dry mandibles (Datta et al., 2015; Vinay et al., 2013; Franklin et al., 2008; Indira et al., 2012; Kharoshah et al., 2010; V Saini et al., 2011).

The mandibular angle may be modified according to environmental and genetic circumstances inherent to each population (Belaldavar et al., 2019). In our study, all mandibular measurements showed sex-related statistical differences. Nevertheless, a study carried out in India (Sharma et al., 2016) showed that no sex-related significant difference was found for the mandibular angle, which is in contrast with the findings presented herein. Except for the mandibular angle, all measurements were found to be greater in males. These findings are consistent with those observed in other populations, such as Israeli (Tunis et al., 2017), Indians (Belaldavar et al., 2019; Upadhyay et al., 2012; Mehta et al., 2020), Chinese (Dong et al., 2015), Koreans (Lin et al., 2014), and European descendants (İlgüy et al., 2014). The fact that the chewing musculature is naturally stronger in males than females may explain the sex-related differences observed in mandibular measurements.

Previous studies examined mandibular measures by computed tomography (CT) imaging (Saini et al., 2011; Dong et al., 2015; Lin et al., 2014; İlgüy et al., 2014; Gamba et al., 2016; Kano et al., 2015). While the measurements were taken digitally on CT scans, the authors observed significant sex-related associations, which further corroborates our data.

In this study, the variables with the highest agreement rates were the height of the left mandibular ramus (74.80%) for males and the bigonial-width (77.60%) for females. On the other hand, the variables with the lowest agreement rates for both sexes were the anterior, right and left mandibular thickness as well as the minimum width of the left mandibular ramus. Therefore, the latter should not be considered accurate parameters to determine the sex of human bones.

In line with our findings, discriminant analyses of samples from several countries have been reported in the literature, including South Africa (81.8%) (Franklin et al., 2008), Korea (88.8%) (Lin et al., 2014), and Brazil (76%-86%) (Lopez-Capp et al., 2018). Regardless of the different populations studied, the mandible was found to be an effective structure for sex estimation.

Several studies have included different ethnic groups in their samples. Brazil, in particular, has a significant miscegenation with diverse genomic influences, among which are the African, European, and indigenous, a reflection of the colonization process (Khedya et al., 2015; Durso et al., 2014; Lima-Costa et al., 2015). This indicates that a comprehensive study with the Brazilian population is needed to understand the particularities of each region/population group across the country. Thus, further anthropological research should focus on specific methodologies designed for the Brazilian population since the results observed in other populations may not be in line with the findings reported herein.

5. Conclusion

The human mandible provides metric elements for accurate sex estimation in the Brazilian population. All variables analyzed in our study were found to be significantly associated with sex. A discriminant analysis indicated a percentage of agreement of the method of 77.50% for males and 80.20% for females.

The equations derived from the discriminant analysis of Brazilian mandibles yielded sex estimates that should be further validated in other population groups. Future studies that apply these equations should follow the methodological protocols described herein. The measurement of each variable should be carried out in the designated anatomical sites and constant values contained in the formulas should not be altered. Lastly, the use of individual equations for each measure or the pooled equation (measures that showed the best sex predilection rates) is suggested.

Acknowledgments

This study was supported by the Science and Technology Foundation of Pernambuco (FACEPE) and the Coordination for the Improvement of Higher Education Personnel (CAPES).

References

Azaroual, M. F., Fikri, M., Abouqal, R., Benyahya, H., & Zaoui, F. (2014). Relationship between dimensions of muscles of mastication (masseter and lateral pterygoid) and skeletal dimensions: study of 40 cases. *International orthodontics*, *12*(1), 111-124.

Belaldavar, C., Acharya, A. B., & Angadi, P. (2019). Sex estimation in Indians by digital analysis of the gonial angle on lateral cephalographs. *The Journal of forensic odonto-stomatology*, *37*(2), 45.

Datta, A., Siddappa, S. C., Gowda, V. K., Channabasappa, S. R., Shivalingappa, S. B., & Dey, D. (2015). A study of sex determination from human mandible using various morphometrical parameters. *Indian Journal of Forensic and Community Medicine*, *2*(3), 158-166.

Dong, H., Deng, M., Wang, W., Zhang, J., Mu, J., & Zhu, G. (2015). Sexual dimorphism of the mandible in a contemporary Chinese Han population. *Forensic science international*, *255*, 9-15.

Durso, D. F., Bydlowski, S. P., Hutz, M. H., Suarez-Kurtz, G., Magalhães, T. R., & Pena, S. D. J. (2014). Association of genetic variants with self-assessed color categories in Brazilians. *PLoS One*, *9*(1), e83926.

Franklin, D., O'Higgins, P., Oxnard, C. E., & Dadour, I. (2008). Discriminant function sexing of the mandible of indigenous South Africans. *Forensic Science International*, *179*(1), 84-e1.

Gamba, T., Alves, M. C., & Haiter-Neto, F. (2016). Mandibular sexual dimorphism analysis in CBCT scans. *Journal of forensic and legal medicine, 38*, 106–110. https://doi.org/10.1016/j.jflm.2015.11.024

Gharehdaghi, J., Baazm, M., Ghadipasha, M., Solhi, S., & Toutounchian, F. (2018). Anthropometric measurements in Iranian men. *Journal of forensic and legal medicine*, *53*, 31-34.

İlgüy, D., İlgüy, M., Ersan, N., Dölekoğlu, S., & Fişekçioğlu, E. (2014). Measurements of the foramen magnum and mandible in relation to sex using CBCT. *Journal of forensic sciences*, *59*(3), 601-605.

Indira, A. P., Markande, A., & David, M. P. (2012). Mandibular ramus: An indicator for sex determination-A digital radiographic study. *Journal of forensic dental sciences*, *4*(2), 58.

James, S. H., & Nordby, J. J. (2002). *Forensic science: an introduction to scientific and investigative techniques*. CRC press.

Kano, T., Oritani, S., Michiue, T., Ishikawa, T., Hishmat, A. M., Sogawa, N., ... & Maeda, H. (2015). Postmortem CT morphometry with a proposal of novel parameters for sex discrimination of the mandible using Japanese adult data. *Legal Medicine*, *17*(3), 167-171.

Kehdy, F. S., Gouveia, M. H., Machado, M., Magalhães, W. C., Horimoto, A. R., Horta, B. L., & Brazilian EPIGEN Project Consortium. (2015). Origin and dynamics of admixture in Brazilians and its effect on the pattern of deleterious mutations. *Proceedings of the National Academy of Sciences*, *112*(28), 8696-8701.

Kharoshah, M. A. A., Almadani, O., Ghaleb, S. S., Zaki, M. K., & Fattah, Y. A. A. (2010). Sexual dimorphism of the mandible in a modern Egyptian population. *Journal of forensic and legal medicine*, *17*(4), 213-215.

Kumar, M. P., & Lokanadham, S. (2013). Sex determination & morphometric parameters of human mandible. *Int J Res Med Sci*, *1*(2), 93-96.

Lima-Costa, M. F., Rodrigues, L. C., Barreto, M. L., Gouveia, M., Horta, B. L., Mambrini, J., & Tarazona-Santos, E. (2015). Genomic ancestry and ethnoracial self-classification based on 5,871 community-dwelling Brazilians (The Epigen Initiative). *Scientific reports*, *5*(1), 1-7.

Lin, C., Jiao, B., Liu, S., Guan, F., Chung, N. E., Han, S. H., & Lee, U. Y. (2014). Sex determination from the mandibular ramus flexure of Koreans by discrimination function analysis using three-dimensional mandible models. *Forensic science international*, *236*, 191-e1.

Lopez-Capp, T. T., Rynn, C., Wilkinson, C., de Paiva, L. A. S., Michel-Crosato, E., & Biazevic, M. G. H. (2018). Discriminant analysis of mandibular measurements for the estimation of sex in a modern Brazilian sample. *International journal of legal medicine*, *132*(3), 843-851.

Mehta, H., Bhuvaneshwari, S., Singh, M. P., Nahar, P., Mehta, K., & Sharma, T. (2020). Gender determination using mandibular ramus and gonial angle on OPG. *Journal of Indian Academy of Oral Medicine and Radiology*, *32*(2), 154.

Pereira, M. G. (2001). Epidemiologia: teoria e prática. In *Epidemiologia: teoria e prática* (pp. 596-596).

Rouquayrol, M. Z., & Almeida Filho, N. (2006). Epidemiologia e Saúde. (4a ed.).

Saini, V., Srivastava, R., Rai, R. K., Shamal, S. N., Singh, T. B., & Tripathi, S. K. (2011). Mandibular ramus: An indicator for sex in fragmentary mandible. *Journal of forensic sciences*, *56*, S13-S16.

Saini, V., Srivastava, R., Rai, R. K., Shamal, S. N., Singh, T. B., & Tripathi, S. K. (2011). Mandibular ramus: An indicator for sex in fragmentary mandible. *Journal of forensic sciences*, *56*, S13-S16.

Sharma, M., Gorea, R. K., Gorea, A., & Abuderman, A. (2016). A morphometric study of the human mandible in the Indian population for sex determination. *Egyptian Journal of Forensic Sciences*, *6*(2), 165-169.

Spradley, M. K. (2016). Metric methods for the biological profile in forensic anthropology: sex, ancestry, and stature. *Academic forensic pathology*, *6*(3), 391-399.

Tunis, T. S., Sarig, R., Cohen, H., Medlej, B., Peled, N., & May, H. (2017). Sex estimation using computed tomography of the mandible. *International journal of legal medicine*, *131*(6), 1691-1700.

Upadhyay, R. B., Upadhyay, J., Agrawal, P., & Rao, N. N. (2012). Analysis of gonial angle in relation to age, gender, and dentition status by radiological and anthropometric methods. *Journal of forensic dental sciences*, *4*(1), 29.

Vinay, G., Mangala Gowri, S. R., & Anbalagan, J. (2013). Sex determination of human mandible using metrical parameters. *Journal of clinical and diagnostic research: JCDR*, *7*(12), 2671.