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Sex Prediction From Metrical Analysis of Macerated Mandibles of Brazilian Adults

Predicción Sexual Mediante Análisis Métrica de Mandíbulas Maceradas de Brasileños Adultos

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SUMMARY: Determining sex may be more difficult in cases such as natural disasters, accidents or situations in which bodies are subjected to high temperatures, when individuals must be identified from their remains. The mandible is a very strong bone, presents high sexual dimorphism and may be useful in forensic identification. The object of the present study was to determine sex by metrical analysis of macerated mandibles of Brazilian adults. We analysed 113 fully dentate macerated mandibles of Brazilian adults, 47 belonging to women and 66 to men. We took 8 measurements using a digital calliper: bicondilar breadth (BC), bigonial breadth (BG), bimental foramina breadth (BM), distance between mental foramen and mandibular base (MF-MB), mandibular ramus height (MRH), maximum mandibular ramus breadth (MaRB), minimum mandibular ramus breadth (MiRB) and mandibular body length (MBL). The t test was used for statistical analysis of independent samples, and a ROC curve was constructed. Direct and stepwise discriminant analysis was carried out. SPSS v.22 software was used, with a significance threshold of 5 %. We observed that all the measurements presented statistically significant differences between the sexes, with greater mean values for men than for women. BG was the measurement which presented the greatest area under curve (AUC), and the highest correct prediction, followed by MRH and BC. The BM distance presented the smallest AUC and lowest correct prediction. The mean correct prediction was 85 % for direct discriminant analysis and 83.2 % for stepwise discriminant analysis, using the BG and MRH measurements. The measurements analysed in this study can be used to determine the sex of Brazilian individuals.

KEY WORDS: Mandible; Sexual prediction; Discriminant analysis.

INTRODUCTION

The principal characteristics of biological identity are sex, age, stature and ethnic origin (Scheuer, 2002). Determining sex is important for forensic anthropology when an unknown individual needs to be identified. Determining sex may be more difficult in cases such as natural disasters, accidents or situations in which bodies are subjected to high temperatures, when individuals must be identified from their remains. The cranium (including the mandible) and the pelvis are considered to be the structures presenting the greatest sexual dimorphism (Sharma *et al*., 2016), with accuracies of 92 % and 95 % respectively (Krogman & Iscan, 1986). The mandible is a bone which forms the lower third of the face (Alves & Cândido, 2016). It is a very important structure for determining sex as it is very strong and presents high sexual dimorphism (Ongkana & Sudwan, 2009).

Some studies have analysed the morphological characteristics of the mandible, observing that the ramus flexure (Kemkes-Grottenthaler *et al*., 2002; Saini *et al*., 2011), gonial eversion (Kemkes-Grottenthaler *et al*.) and shape of the chin (Deana & Alves, 2017) present important sexual dimorphism. However, sexual dimorphism can be more accurately assessed by anthropometric methods, since classification by visual analysis may be more subjective, varying between researchers (Ogawa *et al*., 2013). Morphological features may present variation between different populations; factors such as socio-economic status, environmental and climatic effects, genetic composition, nutritional state and diet may result in some features being more or less accentuated in a given population (Angel, 1976; Krogman & Iscan; Rogers, 2005; Oettlé *et al*., 2009; Evteev

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et al., 2014). It is therefore, important to carry out anthropometric studies in every population in order to have up-to-date information available to aid anthropologists and forensic investigators in determining the sex of an individual. The objective of the present study was to determine sex by metrical analysis of macerated mandibles of Brazilian adults.

MATERIAL AND METHOD

Sample: In the present study we analysed 113 fully dentate macerated mandibles of Brazilian adults, 47 belonging to women and 66 to men. They belonged to the Department of Morphology and Genetics, UNIFESP (Brazil). Mandibles for which there was no information on sex or nationality, those which were partially or completely edentate, and those which were damaged or presented any kind of pathology were excluded from the study.

The researchers were calibrated prior to carrying out the measurements. The following measurements were taken with a digital calliper: bicondilar breadth, bigonial breadth, bimental foramina breadth, distance between mental foramen and mandibular base, mandibular ramus height, maximum mandibular ramus breadth, minimum mandibular ramus breadth and mandibular body length (Table I).

Statistical analysis: Descriptive analysis was by mean value with standard deviation. Measurements were compared using a t test for independent samples. We constructed a ROC curve to analyse the best diagnostic test. We carried out direct and stepwise discriminant analysis and a Fisher discrimination analysis. The discriminant function was obtained for the female and male sexes as follows: Sex = constant + ($r1 \times m1$) + ($r^2 \times m^2$) + ($r^3 \times m^3$)..., where r is the discriminant coefficient and m is the discriminant variable (mandible measurements). In this model, the measurements can be substituted in the 2 functions and the results compared. The diagnosis was carried out as follows: female > male = male; female < male = female; and female = male, sex not defined. The SPSS v.22 software was used, with a significance threshold of 5 %.

Table I. Description and abbreviations of the measurements analysed.

Measurement	Description	Abbreviation
Bicondilar breadth	Distance between the two lateral *condylion*	BC
Bigonial breadth	Distance between right and left *gonion*	BG
Bimental foramina breadth	Distance between the two mental foramina	BM
Distance between mental foramen and mandibular base	The shortest distance from the inferior margin of mental foramen to the mandibular base	MF-MB
Mandibular ramus height	The distance from the highest point on the mandibular condyle to the gonion	MRH
Maximum mandibular ramus breadth	The maximum anteroposterior distance of the mandibular ramus	MaRB
Minimum mandibular ramus breadth	The minimum anteroposterior distance of the mandibular ramus	MiRB
Mandibular body length	Linear distance between *gonion* and *gnathion*	MBL

RESULTS

We observed that all the measurements presented statistically significant differences between the sexes, with greater mean values for males than for females (Table II). No statistical differences were found between sides, therefore the measurements were analysed together using the ROC curve.

BG was the distance presenting the greatest area under curve (AUC) (Fig. 1) (Table III), with good accuracy and the best balance between sensitivity and specificity, followed by MRH and BC. All the other measurements presented AUC of less than 0.700. The BM distance presented the smallest AUC and lowest sensitivity (Fig. 1)

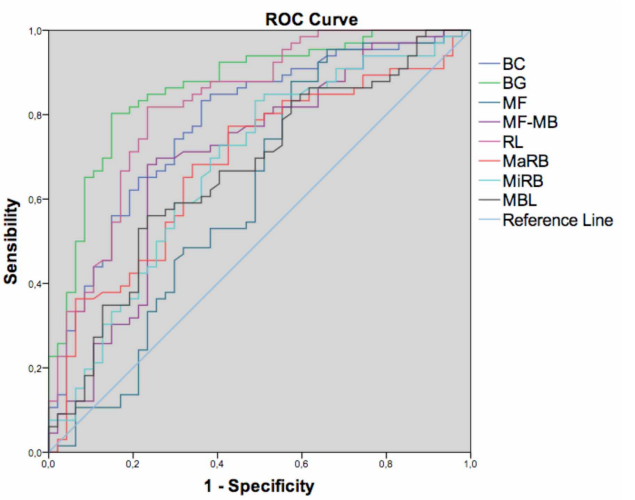

Fig. 1. ROC curve for the measurements analysed.

(Table III). Table III shows the cut-off point (PC), representing the ideal point for sex determination for each measurement analysed in the mandible.

We observed through discriminant analysis that the measurement offering the best prediction of sex was BG (80.5 %), followed by MRH (76.1 %), BC (69.9 %) and MiRB (66.8 %). BM was the measurement which presented the poorest sex prediction (55.8 %) (Table IV). Direct discriminant analysis presented 85.0 % mean correct prediction; stepwise analysis presented 83.2 % mean correct prediction using the BG and MRH measurements (Table V). Table V shows the discriminant function generated for each sex.

Table II. Mean values (in millimetres), standard deviation (SD), Confidence interval (CI) and p-value of the measurements analysed, by sex and side.

Measurement	Sex	Mean	SD	CI (95 %)	p-value
BC	Males	118.84	5.59	-7.49 -3.47	0.00
	Females	113.35	4.88		
BG	Males	96.38	5.19	-10.03 -6.14	0.000
	Females	88.29	5.07		
BM	Males	44.11	2.28	-2.20 -0.09	0.032
	Females	42.93	3.36		
MF-MB	Males	13.83	1.49	-1.25 -0.45	0.000
	Females	12.97	1.51		
MRH	Males	62.26	4.35	-7.41 -4.83	0.000
	Females	56.13	5.16		
MaRB	Males	43.21	4.41	-3.52 -0.84	0.002
	Females	41.03	5.41		
MiRB	Males	31.45	3.24	-3.12 -1.25	0.000
	Females	29.26	3.68		
MBL	Males	85.34	4.64	-4.49 -1.98	0.000
	Females	82.10	4.74		

Table III. Analysis of the ROC curve for the measurements taken in the mandible.

Measurement	AUC	CP	A	SS	SP
BC	0.778	females<114.260>males	75.2 %	63.8 %	83.3 %
BG	0.865	females<92.920>males	82.3 %	85.1 %	80.3 %
BM	0.613	females<41.750>males	69.0 %	42.6 %	87.9 %
MF-MB	0.698	females<13.430>males	71.7 %	76.6 %	68.2 %
MRH	0.824	females<59.080>males	79.6 %	76.6 %	81.8 %
MaRB	0.684	females<40.360>males	69.0 %	57.4 %	77.3 %
MiRB	0.680	females<30.802>males	68.7 %	58.2 %	76.5 %
MBL	0.666	females<85.150>males	76.6 %	56.1 %	55.4 %

AUC, Area under curve; CP, Cut-off point; A, Accuracy; SS, Sensitivity; SE, Specificity.

Table IV. Discriminant analysis of measurements analysed.

Measurement	λ Wilks'	Correct prediction		Mean correct prediction
		Males	Females	
BC	0.791	68.2 %	72.3 %	69.9 %
BG	0.620	80.3 %	80.9 %	80.5 %
BM	0.959	59.1 %	40.9 %	55.8 %
MF-MB	0.927	60.6 %	69.1 %	64.2 %
MRH	0.707	77.3 %	74.5 %	76.1 %
MaRB	0.953	60.6 %	67.0 %	63.3 %
MiRB	0.909	70.5 %	61.7 %	66.8 %
MBL	0.895	62.1 %	62.8 %	62.4 %

Table V. Sex prediction and equation using stepwise discriminant analysis.

Measurements	Fisher coefficient		_ Wilks'	P-value	Correct prediction		Mean correct prediction
	Males	Females			Males	Females	
Stepwise							
BG	3.363	3.088	0.500	0.000	84.8 %	80.9 %	83.2 %
MRH	2.264	2,017					
Constant	-233.715	-193.672					
Function Males	-233.715+ (3.363 _ BG) + (2.264 _ MRH)						
Function Females	-366.300 + + (3.088 _ BG) + (2.017 _ MRH)						
Direct							
BC	2.733	2.640	0.491	0.000	87.9 %	80.9 %	85.0 %
BG	1.567	1.306					
BM	2.011	2.157					
MF-MB	1.833	1.952					
MRH	2.073	1.820					
MaRB	-0.306	-0.265					
MiRB	-1,481	-1.585					
MBL	-1,863	1.855					
Constant	-410.153	-366.024					
Function males	410.153 + (2.733 x BC) + (1.567 x BG) + (2.011 x BM) + (1.833 x MF-MB) + (2.073 x MRH) + (-0.306 x MaRB) + (-1.481 x MiRB) +(-1.863x MBL)						
Function females	-366.024 + (2.640 x BC) + (1.306 x BG) + (2.157 x BM) + (1.952 x MF-MB) + (1.820 x MRH) + (-0.265 x MaRB) + (-1.585 x MiRB) + (1.855 x MBL)						

DISCUSSION

Biological identification of sex is one of the most important techniques established by forensic science; it is essential in the recognition of individuals officially declared dead in situations such as mass disasters, atrocities and criminal investigations (de Oliveira *et al*., 2015; Schmeling *et al*., 2016).

The reliability and accuracy of sex prediction are directly dependent on the anatomical region of the remains (Mai *et al*., 2005). The mandible is originally bipartite, with each half developing absolutely independently (Testut & Latarjet, 1968). It presents marked sexual dimorphism due to the development of the muscular-skeletal system, especially the chewing muscles attached to the mandible (Hu *et al*., 2006; Franklin *et al*., 2007). Different life styles and diets, as well as chewing habits and hormonal factors, affect the size and shape of the mandible (Hu *et al*.); this may result in differences in mandible morphology between different populations.

Various methods have been used to determine the accuracy of sexing by mandible analysis. Initially the simplest methods are applied, since before a more expensive or complex method is adopted, several variables must be considered, such as the conservation state of the skeleton, the clarity of the characteristics present and the precision required in each case (Krishan *et al*., 2016). Sex determination by analysis of morphological characteristics is quicker and easier, but it is more difficult to obtain a decision because the nutrition, occupation, descent and geographical origin of the individual must be considered (Kranioti *et al*., 2008). Nonetheless, in the hands of an expert observer non-metric assessment may offer great accuracy in determining sex (Krishan *et al*.). On the other hand, metric analysis is more accurate than visual analysis; however there are specific measurements for each population subject to trends in modern habits, so every population must be analysed separately (Dayal *et al*., 2008).

Sexual dimorphism in the mandible can be observed in individuals aged over 16 years (de Oliveira *et al*.), therefore only adult individuals aged over 18 years were included in this study. Only completely dentate mandibles were selected due to the morphological alterations which may result from tooth loss (Alves, 2009; Alves & Cândido).

In the present study BG presented the greatest AUC and the best balance between sensitivity and specificity, corroborating previous studies in Brazilian populations (Gamba *et al*., 2016; Lopez-Capp *et al*., 2018). The mean values found for BG in the present study were similar to those found for individuals from Northern Thailand (Ongkana & Sudwan) and for Black South Africans (Dayal *et al*.) (Table VI). Marinescu *et al.* (2013), in individuals from Romania, and Lopez-Capp *et al*. in Brazilian individuals, found that BG was the measurement which presented the greatest sexual dimorphism, corroborating the findings of the present study.

In a study of individuals of European descent, the researchers observed that this measurement offers good sex prediction and can be used for sexing (Ilgüy *et al*., 2014). In discriminant analysis, we observed that this measurement presented the greatest mean correct prediction, with 80.5 %, corroborating the findings of Lopez-Capp *et al*.

In an earlier study in a Brazilian population, the researchers observed that BC presented great sexual dimorphism (Gamba *et al*.; Lopez-Capp *et al*.); this was corroborated by the present study, where we found good sex determination (AUC: 0.778) and good accuracy (75.2 %). In discriminant analysis we observed that this measurement achieved 69.9 % mean correct prediction, higher than reported in another study also carried out on a Brazilian population (66 %) (Lopez-Capp *et al*.). The mean values found for BC in the present study were lower than those foundin Chinese (Dong *et al*., 2015) and Japanese populations (Ongkana & Sudwan); similar to those reported for Brazilians (Lopez-Capp *et al*.) and Romanians (Marinescu *et al*.), and higher than reported in another study in a Brazilian population (Gamba *et al*.) (Table VI). In Chinese individuals, Dong *et al*. observed that this measurement presented great sexual dimorphism with an accuracy of 75 % for males and 83.2 % for females. For individuals of European descent on the other hand, it was observed that this measurement was of no assistance in determining sex (Ilgüy *et al*.).

de Oliveira *et al*. assessed sexual dimorphism and age from analysis of the MRH and reported that this measurement was reliable only for estimating the age of the individual, but presented no difference between sexes. However, other studies in Brazilian populations (Gamba *et al*.; Lopez-Capp *et al*.) observed that this measurement presented great sexual dimorphism; this corroborates the findings of the present study, where this measurement presented the second best AUC, good balance between sensitivity and specificity, and good accuracy. Discriminant analysis of this measurement in the present study showed a value of 76.1 % mean correct prediction, higher than reported by Lopez-Capp *et al*. also in a Brazilian population, with values of 70 % for the right side and 67 % for the left. Values reported for Black South Africans (Dayal *et al*.), Brazilians (Gamba *et al*.) and Chinese (Dong *et al*.) were lower than found in our study. Similar values to those found in the present work were reported for individuals of European descent (Ilgüy *et al*.) and in another study on a Brazilian population (Lopez-Capp *et al*.). In populations from Japan (Ogawa *et al*.), Northern Thailand (Ongkana & Sudwan) and Egypt (Kharoshah *et al*., 2010), the MRH values were higher than those found for the population analysed in our study (Table VI). In a study of individuals of European

Table VI. Mean values in millimetres reported in the literature. CBCT cone-beam computarized tomography, R right, L left.

Author	Origin	Age	Study material	Sex	N	Measurements							
						BC	BG	BM	MF-MB	MRH	MaRB	MiRB	MBL
Dayal *et al*., 2008	Black South Africans	20-70	Dry mandibles	Males	60	-	96.70	-	-	54.89	-	36.00	85.53
				Females	60	-	89.75	-	-	48.81	-	34.25	81.42
Dong *et al*., 2015	China	20-65	CBCT scans	Males	96	130.0	100.2	49.73	15.29	45.41	-	-	86.45
				Females	107	121.4	93.59	47.22	14.0	41.99	-	-	81.46
Gamba *et al*., 2016	Brazil	18-60	CBCT scans	Males	74	94.96	118.48	-	-	54.36	-	28.70	70.37
				Females	86	87.47	100.03	-	-	49.41	-	28.91	67.14
Ilgüy *et al*., 2014	European descent	18-85	CBCT scanner	Males	66	120.79	94.77	-	-	61.67	-	28.08	71.86
				Females	95	116.23	100.33	-	-	57.75	-	29.89	67.73
Kharoshah *et al*., 2010	Egypt	06-60	CBCT scanner	Males	165	108.90	104.80	-	-	65.10	-	28.70	76.20
				Females	165	99.60	100.80	-	-	64.70	-	27.96	83.10
Lopez-Capp *et al*., 2018	Brazil	18-104	dry mandibles	Males	47	117.08	92.63	-	-	60.54R 59.26L	32.46	30.46	69.81
				Females	43	112.07	87.02	-	-	54.73R 54.09L	31.02	28.94	67.02
Marinescu *et al*., 2013	Romanian	20-89	dry mandibles	Males	100	120.00	102.40	-	-	-	-	-	-
				Females	100	113.10	92.80	-	-	-	-	-	-
Ogawa *et al*., 2013	Japan	>19	dry mandibles	Males	73	125.00	102.60	-	-	64.30	-	-	-
				Females	40	121.20	95.50	-	-	58.30	-	-	-
Ongkana & Sudwan, 2009	Northern Thailand	23-93	dry mandibles	Males	68	123.80	96.80	-	-	68.10	121.30	32.80	83.20
				Females	34	116.10	89.70	-	-	62.60	114.70	31.40	79.20

descent, the researchers observed that this measurement offers good sex prediction, corroborating the results of the present study (Ilgüy *et al*.).

In the present study, the other measurements taken (BM, MF-MB, MaRB, MiRB and MBL) presented AUC less than 0.700, with accuracy varying between 76.6 % and 68.7 %. The cut-off point presented in Table III can be used as a reference for determining sex from the mandible of unknown individuals. In discriminant analysis, BM, MF-MB, MaRB, MiRB and MBL presented sexual dimorphism with correct prediction varying between 66.8 % and 55.8 %.

Direct discriminant analysis achieved 85 % sex prediction, whereas stepwise analysis achieved 83.2 % mean correct prediction using BG and MRH, with better sex prediction in men than women. The correct sex prediction found in the present study agrees with previous studies. Dong *et al*. also found greater accuracy in sex prediction using the direct method (84.2 %) than the stepwise method (83.3 %). Lopez-Capp *et al*. found between 76 % and 83 % in an analysis of Brazilian macerated mandibles. In Egyptians, Kharoshah *et al*. found 83.9 % correct prediction using MRH, BC, MiRB and the gonial angle. In individuals of European descent, Ilgüy *et al*. found 83.2 % predictive accuracy using MRH, MBL, BG and gonial angle. Similar values were also found for Romanians (Marinescu *et al*.), with 84 % accuracy obtained from three measurements: chin height, BG and BC. In Black South Africans (Dayal *et al*.), accuracy of 85 % was achieved using BG, MRH and total mandibular length. Slightly higher predictive accuracy than that found in our study was reported by Zheng *et al*. (2018) in individuals from north-eastern China, with mean correct prediction of 87.4 %. The accuracy was slightly higher for women (89 %) than men (85.7 %). They used 7 measurements in the final correct prediction: mandibular angle, area of mandibular foramen, BG, distance between left and right coronoid processes, minimum height, mandibular notch and palatal breadth. High accuracy of 95.1 % was reported in another study in a Brazilian population (Gamba *et al*.), using MRH, BC, BG and gonial angle. Values slightly lower than ours were reported by Carvalho *et al*. (2013), who found 78.13 % for females and 76.47 % for males in an analysis of Brazilian mandibles using BG and MRH.

In the present study, all the measurements analysed presented sexual dimorphism, with greater values for men than for women. BG, MRH and BC presented better sex prediction in both discriminant analysis and the ROC curve; this corroborated previous studies also carried out in Brazilian populations (de Oliveira *et al*.; Gamba *et al*.; Lopez-Capp *et al*.).

CONCLUSION

The mandibles studied presented great sexual dimorphism under metric analysis. Of the measurements taken, BG, MRH and BC presented great accuracy in predicting sex, while BM presented the lowest predictive power. The measurements analysed in this study can be used in determining the sex of Brazilian individuals.

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RESUMEN: En casos de desastres naturales, catástrofes o situaciones en las cuales los cuerpos son sometidos a altas temperaturas la identificación sexual queda más difícil, siendo necesaria la identificación de los individuos a partir de restos mortales. La mandíbula es un hueso muy resistente, que presenta gran dimorfismo sexual, pudiendo ser útil en la identificación forense. El objetivo de este estudio fue determinar la predicción sexual mediante el análisis métrico de mandíbulas maceradas de individuos brasileños adultos. Fueron analizadas 113 mandíbulas maceradas completamente dentadas de Brasileños adultos, siendo 47 mujeres y 66 hombres. Con un cáliper digital fueron evaluadas 8 medidas: amplitud bi-condilar (BC), amplitud bi-gonial (BG), amplitud entre forámenes mentonianos (BM), distancia entre el foramen mentoniano y la base de la mandíbula (MF-MB), altura de la rama mandibular (MRH), anchura máxima de la rama mandibular (MaRB), anchura mínima de la rama mandibular (MiRB) y longitud del cuerpo de la mandíbula (MBL). Para análisis estadístico se utilizó la prueba t para muestras independientes. Además se construyó una curva ROC. Se realizó análisis discriminante directo y por pasos. Se utilizó el software SPSS V.22, considerando umbral de significación de 5 %. Se observó que todas las medidas presentaron diferencias estadísticas entre sexos, siendo los valores medios encontrados para hombres mayores que los encontrados para mujeres. La BG fue la medida que presentó mayor área bajo la curva (AUC) y mayor predicción, seguido de la MRH y de la BC. La distancia BM fue la medida que presentó la menor AUC y menor predicción. La correcta predicción para el análisis discriminante directo alcanzó el 85 % y por pasos alcanzó el 83.2 % utilizándose las medidas BG y MRH. Las medidas analizadas en este estudio pueden ser utilizadas en el diagnóstico sexual de individuos Brasileños.

PALABRAS CLAVE: Mandíbula; Predicción sexual; Análisis discriminante.

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