Morphometric analysis of the supraorbital region for sexual dimorphism: A study on Brazilian adult dry skulls

ABSTRACT

Introduction: Pelvis, long bones, and skull are good indicators of sexual dimorphism. In the skull, the supraorbital region is considered a highly sexually dimorphic part. Thus, the present study aimed to analyze the sexual dimorphism of Brazilian adult dry skulls using conventional and geometric morphometry.

Materials and Methods: Conventional morphometry was performed on 179 skulls, through the analysis of six linear measurements. For geometric morphometry, 89 skulls (right side) were selected and seven landmarks were considered. Generalized procrustes analysis, principal component analysis, and linear discriminant analysis were then carried out.

Results: All linear measurements presented differences between both sexes. Geometric morphometry showed that 77.05% of the sample variation could be explained by the first three principal components. Moreover, considering the centroid size, there was a difference in shape between the sexes. Geometric morphometry classified sex correctly in 77.32% of the skulls and conventional morphometry from 60.89% to 73.74%.

Conclusions: According to the analyses, the supraorbital region presents significant sexual dimorphism in Brazilian adult dry skulls. Moreover, it can be analyzed efficiently by both conventional and geometric morphometry, although the latter seems to be slightly more accurate.

Keywords: Frontal bone, sex characteristics, skull

INTRODUCTION

Pelvis, skull, and long bones are good indicators of sexual dimorphism. In cases in which the pelvis and long bones cannot be located or there is not enough conservation for analysis, skull bones are the most efficient ones for sex determination.[1-3] The external surface of the inferior (facial) portion of the frontal bone is shaped mainly by the supraorbital region, which presents a complex morphology[4] and can be considered an important highly sexually dimorphic part of the skull.[2,5-7]

Male skulls generally have larger and more robust superciliary arches, whereas female ones present mild-to-moderate prominence. Moreover, the glabella shows greater variation between the sexes, being more prominent in males.[8] The supraorbital region is not only valuable as an indicator of sexual dimorphism but also to predict individual development since it is related to hormonal production, more specifically androgens.[9]

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Considering that sexually dimorphic cranial features are traditionally assessed visually and scored using an ordinal

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scale, a highly subjective method,[10] and that the Brazilian population has unique characteristics due to marked miscegenation,[11] conducting anthropology studies is not a simple task. Although the supraorbital region is considered useful for investigating postmortem remains of multi-ethnic populations,[7,12-14] other techniques such as geometric morphometry are of paramount importance since they allow efficient analyses of shape.[15]

In light of these facts, the present study aims to conduct both conventional and geometric morphometric analyses of the supraorbital region of Brazilian dry skulls considering sexual dimorphism.

MATERIALS AND METHODS

Ethical issues and sample selection

This study was conducted using 403 Brazilian adult dry skulls from the anatomical collection of skulls of the Federal University of São Paulo (São Paulo, Brazil), "*Museu de Crânios*," after approval by the local Research Ethics Committee (Ref. No. 36246420.2.0000.5505, dated 23 October 2020). Those with deformities from pathology, trauma, cranial surgery, or damage to the supraorbital region were excluded from analyses. So, 179 skulls were actually evaluated (112 males and 67 females older than 18 years; mean age = 38.40 years, standard deviation = 16.44 years).

Conventional morphometry

All the skulls were evaluated by only one experienced observer by using a digital caliper (Digimess, 100.174BL, Digimess Instrumentos de Precisão Ltda, São Paulo, SP, Brazil; accuracy ±0.03 mm). Each measurement was performed three times but only the mean value from them was considered.

Initially, two virtual points were determined in every skull. These points were defined by placing the measuring arms of the digital caliper concomitantly on the landmarks frontotemporale (the most anterior point on the temporal line of the frontal bone—ft) and frontomalaretemporale (the most posterolateral point of the frontozygomatic suture—fmt) and the distance halfway between them was then considered point A on the left side and point B on the right side.[10,16] Next, the following morphometric analyses[10,17] were carried out bilaterally in all specimens: [Figure 1]

1) The distance from A or B to the outermost projection of the glabella (point G);
2) The distance from A or B to the outermost projection of the superciliary arch (point SA);
3) The distance between the temporal lines of the frontal bone, i.e., from A to B;

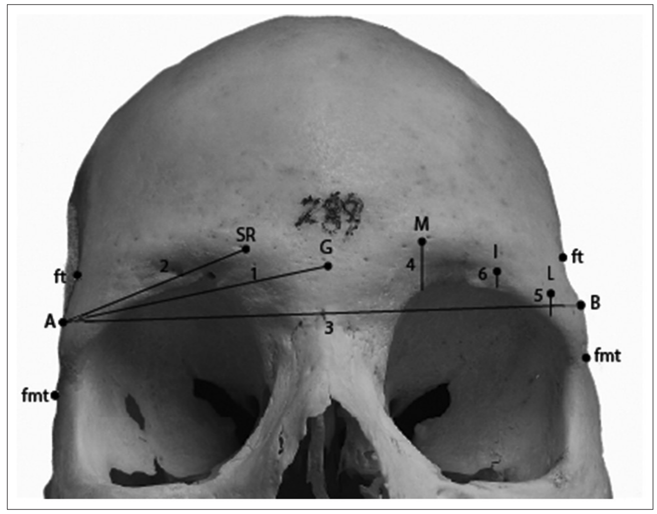

Figure 1: Points and measurements used for conventional morphometric analysis. Note that some landmarks are well-established craniometrics points and others were determined according to anatomic structures and planes

4) Considering a parasagittal plane (a plane virtually situated parallel to the sagittal plane), the maximum superoinferior height of the superciliary arch, i.e., the distance from point M (the outermost projection of the medial region of the superciliary arch) to the supraorbital margin—"medial supraorbital height";
5) Considering a parasagittal plane (a plane virtually situated parallel to the sagittal plane), the maximum superoinferior height of the supraorbital trigone, i.e., the distance from point L (the outermost projection of the lateral region of the superciliary arch) to the supraorbital margin—"lateral supraorbital height";
6) Considering a parasagittal plane (a plane virtually situated parallel to the sagittal plane), the distance from the point I (located halfway between points L and M) to the supraorbital margin—"intermediate supraorbital height".

The data were tabulated into Microsoft Office Excel™ spreadsheets (Microsoft Corporation, Santa Rosa, California, USA) and analyzed descriptively and inferentially in the Statistics Package for Social Sciences—version 22.0™ (IBM, Armonk, USA) and Past™—version 4.03.[18] When applicable, P values of less than 0.05 were regarded as statistically significant.

Geometric morphometry

Among the skulls previously evaluated, the more representative ones (i.e., those without fractures or damages to any region) were selected for geometric morphometry analysis, totalizing 89 specimens (49 males and 40 females).

Firstly, the specimens were placed on a sheet of graph paper and then photographed. Image deformation obtained from the lens of a Finepix S1800 camera (Fujifilm Holdings Corporation, Tokyo, Japan) could then be identified by digital measurements in the TPSDig2™—version 2.30 (the State University of New York at Stony Brook, New York, USA). Following, the skulls were positioned with the right side facing the camera, 24 cm away from the camera lens, and with the mastoid process and the alveolar maxillary processes positioned perpendicularly to a straight line in relation to the camera lens. The points depicted in Figure 2 were used for analysis in the TPSDig2™: 1) Glabella (craniometric landmark); 2) Nasion (craniometric landmark); 3) Frontomalare orbitale (craniometric landmark); 4) Frontomalare temporale craniometric landmark); 5) Frontotemporale (craniometric landmark)[16] [Figure 2a]; 6) 30° angle between the glabella and the frontotemporale (a semilandmark determinated by the authors) [Figure 2b]; 7) 60° angle between the glabella and the frontotemporale (a semilandmark determinated by the authors) [Figure 2c].

After digitizing the landmarks, a generalized procrustes analysis was performed. Then, the covariance matrix was generated and principal component analysis (PCA) was performed using MorphoJ™—version 1.07a.[19] Simultaneously, relative warps were generated by TPSRelw™—version 1.53[20] for evaluating size variation, and centroid size was used for evaluating the size of each region.[19,21] Linear discriminant analysis was conducted using Past™—version 4.03.[18] When applicable, *P* values of less than 0.05 were regarded as statistically significant.

RESULTS

Conventional morphometry

All the measurements showed statistically significant differences between male and female skulls, according to the independent samples t test [Table 1]. The linear discriminant analysis for each analysis (both antimeres) is shown in Table 2, presenting values from 60.89% to 73.74% according to the correct sex classification.

Geometric morphometry

Multivariate analysis of variance (MANOVA) of the first ten principal components (PCs) showed a statistically significant difference between the shape of the supraorbital region of male and female skulls (Wilks' lambda = 0.57, $p = 2.47e^{-7}$). Figure 3 shows that, although the distribution of skulls of both sexes was homogeneous on the PC1 and PC2 axes, the averages from females and males diverge. Moreover, female skulls were positioned lower than male ones on the vertical axis (PC2). Lastly, the first three PCs [Figure 4] were responsible for 77.05% of the observed variance: PC1, eigenvalue = 0.014, variance = 42.62%;

Table 1: Results, in millimeters, from conventional morphometric analysis regarding sexual dimorphism

Measurements	Skulls				*P*
	Male		Female		
	Mean	Standard deviation	Mean	Standard deviation	
1—right	54.64	2.81	52.87	2.54	<0.001*
1—left	53.64	2.91	51.46	2.74	<0.001*
2—right	39.37	3.27	37.14	2.84	<0.001*
2—right	37.99	3.08	35.72	2.90	<0.001*
3—right	100.57	4.78	96.95	4.07	<0.001*
4—right	11.94	1.72	10.36	1.72	<0.001*
4—left	12.27	1.73	10.73	1.67	<0.001*
5—right	5.15	0.94	4.70	0.87	0.002*
5—left	5.04	0.92	4.50	0.78	<0.001*
6—right	5.83	1.32	4.80	0.93	<0.001*
6—left	5.65	1.26	4.58	0.94	<0.001*

*Statistically significant value—independent samples *t* test

Table 2: Using linear discriminant analysis for conventional morphometry, rates of correct sex classification

Measurements	Accuracy (%)
1—right/left	65.36
2—right/left	71.5
3—right/left	64.25
4—right/left	73.74
5—right/left	60.89
6—right/left	69.27

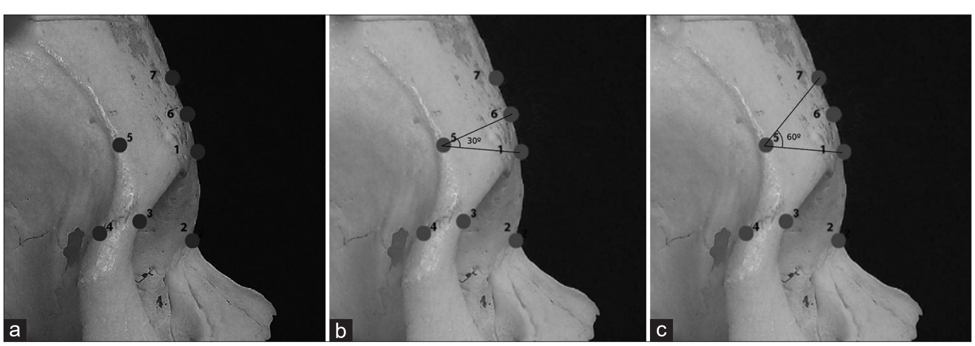

Figure 2: Points used for geometric morphometry analysis. (a) Well-established craniometrics points as landmarks. (b) A semilandmark determinated by the authors: 30° angle between the glabella and the frontotemporale. (c) A semilandmark determinated by the authors: 60° angle between the glabella and the frontotemporale

PC2, eigenvalue = 0.007, variance = 21.22%; PC3, eigenvalue = 0.004, variance = 13.20%.

The size of the region was analyzed using the independent samples t test and showed a statistically significant difference between the size of the centroids between male and female individuals ($p < 0.001$).

Figures 5 and 6 graphically illustrate the differences in the shape of the supraorbital region of the skulls. Figure 5 represents the first two relative warps, which explained 68.91% of the total sample variation. By means of vectorial estimation of the morphological variation for the extremities of the axes, the possible amplitude of the difference in shape could be identified concerning the sample and taking into account the first two relative warps. Figure 6 summarizes the difference in shape, in which male skulls had a more projected glabella and a sharper curvature of the frontal bone.

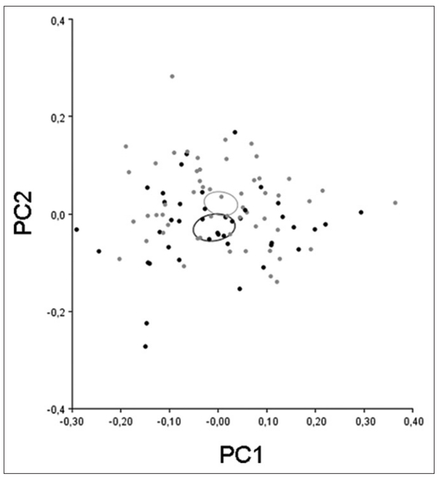

Figure 3: Scatter plot of individuals between the PC1 and PC2 axes and ellipses of the means (confidence interval = 95%). In grey are the male skulls and in black are the female ones. PC: principal component

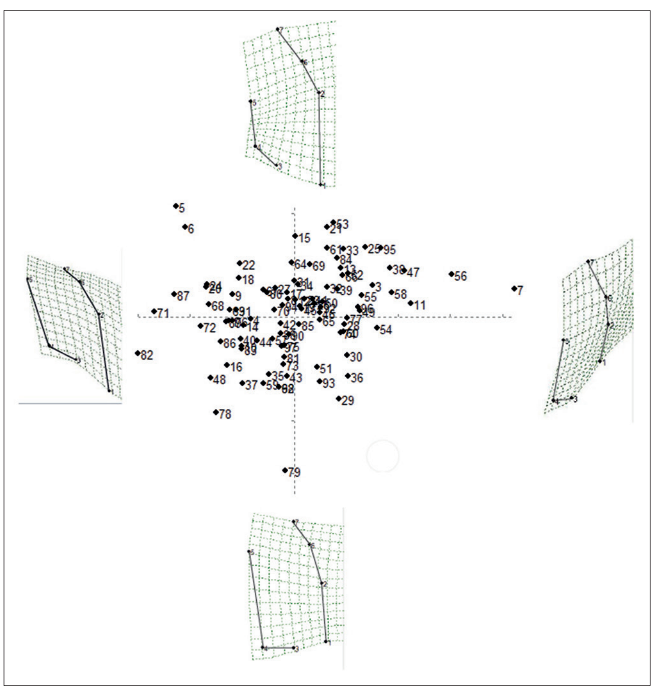

Figure 5: Representation of the first (horizontal axis) and second relative warps (vertical axis). Shape estimation of the skulls that would be in the extremity of the axes

The linear discriminant analysis resulted in a value of 77.32% concerning the correct sex classification.

DISCUSSION

The "*Museu de Crânios*" of the Federal University of São Paulo presents the largest number of identified skulls in Brazil, a country with about 200 million inhabitants marked by intense miscegenation due to immigration.[11,22] Although there is a consensus in the literature that human skull morphology is related to the population origin,[4,5,19] very few studies have addressed Brazilians. Moreover, most of them have used

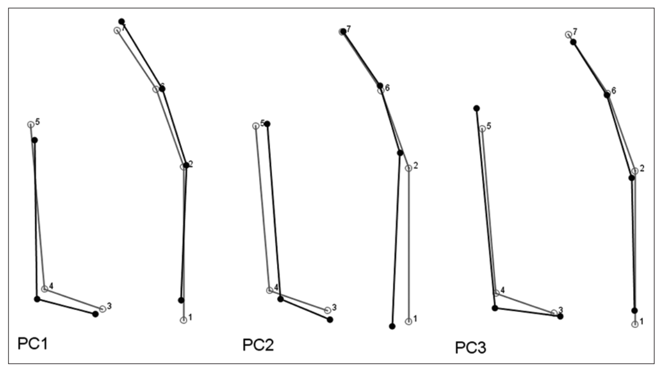

Figure 4: Graphical representation of the variation in the shape of the supraorbital region concerning the first three principal components of male and female skulls. In grey are the male skulls and in black are the female ones. PC: principal component

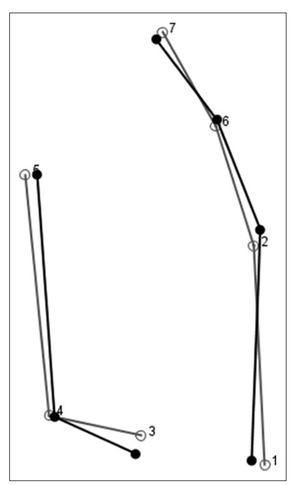

Figure 6: Shape differences in the configuration between mean female and male skulls. In grey are the male skulls and in black are the female ones

conventional morphometry.[23-26] To the best of the authors' knowledge, the present study is the first one combining both morphometry methods for studying the supraorbital region of Brazilian individuals, an important highly sexually dimorphic part of the skull.[8,10]

Conventional morphometry can evaluate only partially the shape of the objects since linear angles and distances do not effectively represent the real anatomy (e.g., the existence or not of bone projections).[27] On the other hand, geometric morphometry provides analyses of shape and size separately.[28]

By using conventional morphometry, all the linear measurements evaluated showed statistically significant differences between male and female skulls, the same reported by a study in the USA.[10] Through geometric morphometry, the shape and size of the supraorbital region also presented a significant difference between both sexes. PCA demonstrated that Brazilian skulls present about 77% of the shape variation explained by the first three PCs. A study in Colombia[13] and another one in the USA[7] reported that this variation could be explained mainly by the first two PCs (82% and 84%, respectively) while the others were less important for shape variation. Therefore, as each PC can be considered as a vector that summarizes the variation in the data,[29] Brazilian skulls probably present a more complex variation in shape concerning the supraorbital region.

By evaluating the relative warps, the first two explained about 70% of the anatomical variation. The figures resulting from this technique depicted the trends of variation through deformation in shape.[20] Thus, the results confirmed that there is a variation in the curvature of the frontal bone, as well as in the glabella, of male and female Brazilian skulls.

Discriminant function analysis showed that geometric morphometry is better to classify the Brazilian skulls into sex than linear measurements from conventional morphometry. However, both morphometry analyses presented a relatively high success rate in relation to sex classification. Studies in Colombia, USA, and Germany also assessed the supraorbital region by geometric morphometry and reported higher degrees of accuracy in classifying different samples into sexes: 84.31%,[13] 79.8%,[7] and 79.1%.[14]

Although animal studies suggest that geometric morphometry is considered a convenient, low-cost, and quick-to-perform technique,[30-32] it requires sophisticated statistical approaches, which would make it a time-consuming procedure and could discourage its use routinely.[33] Mikery *et al*.[34] showed similar results when both conventional and geometric morphometry were compared but the latter required more time and effort. On the other hand, given the present study, the authors can affirm that analyses of conventional morphometry were much easier and quicker to perform, with no need for special and complex equipment.

CONCLUSION

According to the analyses, the supraorbital region presents significant sexual dimorphism in Brazilian adult dry skulls. Moreover, it can be analyzed efficiently by both conventional and geometric morphometry, although the latter seems to be slightly more accurate.

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Conflicts of interest
There are no conflicts of interest.

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