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Original Research Article

Frontal Bone Morphometry: A Standardized Protocol in Dry Skulls

Valeria Cifuentes-Cobo[a] , Alejandra Fula-Ruiz[a] , Daniela Botero-González[b*]
[a]Faculty of Health Science, Universidad Tecnológica de Pereira, Pereira, Colombia. ORCID: 0009-0002-9107-7574 & 0009-0000-6099-5191. [b]Department of Basic Medical Sciences, Faculty of Health Science, Universidad Tecnológica de Pereira, Pereira, Colombia. ORCID: 0000-0002-0156-4997.

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Abstract

Introduction: Frontal bone is a crucial component of facial architecture. It has evolved and changed in modern humans, modifying the skeletal phenotype. This makes the bone a key structure for human body morphological analysis. **Aims:** To establish a replicable frontal bone morphometry and to compare these dimensions with those from other populations. **Material and methods:** Fifty adult dry frontal bones were measured using anatomical landmarks and four measuring tools. One angular and eight linear measurements were used to determine bone sex and assess its morphometry. **Results:** Twenty-six bones were male and twenty-four were female. Average length of 12.5±0.6 centimeters. Supraorbital foramen height right side 1.8±0.3 millimeters and left side 1.7±0.3 millimeters. Supraorbital foramen width 3.5±1 millimeters for right side and 3.7±1.3 millimeters for left side. Orbits distance 26.6±2.6 millimeters. Right zygomatic process width 7.1±1.2 millimeters and left side 7.1±1.1 millimeters. The right zygomatic process width differs between male and women ($p \leq 0.0068$). **Conclusion:** A standardized morphometric protocol for dry human skulls' frontal bone was established. Results were compared with individuals of both sexes and different populations.

1. Introduction

The frontal bone is a key component of facial architecture, playing a crucial role in the transition between the facial skeleton and the skull.[1] These bone has evolved with changes in brain size, cranial base flexion, and facial retraction, making it essential for morphological and functional balance in modern humans.[1-2] Disciplines such as anatomy, anthropology, forensics and clinical sciences (orthodontics, ophthalmology, orthopedics, radiology, neurosurgery, etc.) rely heavily on understanding the development and growth of individual skull bones. For example, gender determination often involves analyzing skull´s sexually dimorphic features, such as mastoid triangle, foramen magnum, internal acoustic meatus, temporal zygomatic, and frontal bone, especially when pelvic bones are unavailable.[3] Studies have demonstrated the utility of craniometric analysis for sex determination, with the frontal bone's morphology

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***Corresponding author:** Daniela Botero-González; Department of Basic Medical Sciences, Faculty of Health Science, Universidad Tecnológica de Pereira, Pereira, Colombia; email: dbotero@utp.edu.co; Contact no.: +57 310 3924606.

being particularly informative. Other studies have shown that osteological features, dimensional parameters, and specific angular measurements are useful for sex estimation. A more gracile and less sloped frontal bone may suggest a female skull, whereas a more sloped frontal bone likely indicates a male skull.[4,-7] The aim of this study was to establish a replicable frontal bone morphometry and to compare these dimensions with those from other populations.

2. Materials and methods

Fifty adult dry frontal bones unknown sex/age were measured for this descriptive observational cross-sectional study. These bones were obtained as convenience samples from the Anatomy Laboratory of tertiary healthcare centre, Colombia. According to the Institutional Ethical Committee, this was classified as exempt from ethical review under institutional guidelines. Measurements were taken using the following tools: a digital caliper (Ubermann, Chile) for recording breadth, height, and length in millimeters (mm); a measuring tape (Stanley Black & Decker, Inc., Seattle, USA) to obtain length in centimeters (cm); a protractor and ruler (Faber-Castell, Guanajuato, México) to collect angular measurements in degrees (°); and a digital camera was used to document the bones photographically. All data were recorded in Microsoft Excel® (version 2205).

Sex classification followed the criteria described by Perlaza (2014) ,[8] where the frontal bone is convex in males and flat in females, see **Figure 1A and 1B**. Consistent with Koelzer et al. (2019) ,[3] frontal bone inclination was also used to determine sex, see **Figure 1C.** Morphometric analysis included frontal length measured with a tape, and supraorbital foramen height and width, orbital distance, and zygomatic process width measured with a digital caliper, see **Figure 2**.

Figure 1. Morphological features of the frontal bone. A. Female morphology. B. Male morphology. C. Frontal angle measurement.

Figure 2. Frontal bone morphometric parameters. A. Frontal length (red), supraorbital foramen height (purple), width (green), orbital distance (yellow), and zygomatic process width (blue). B. Supraorbital foramen height (yellow) and width (red). C. Orbital distance (red). D. Zygomatic process width (red).

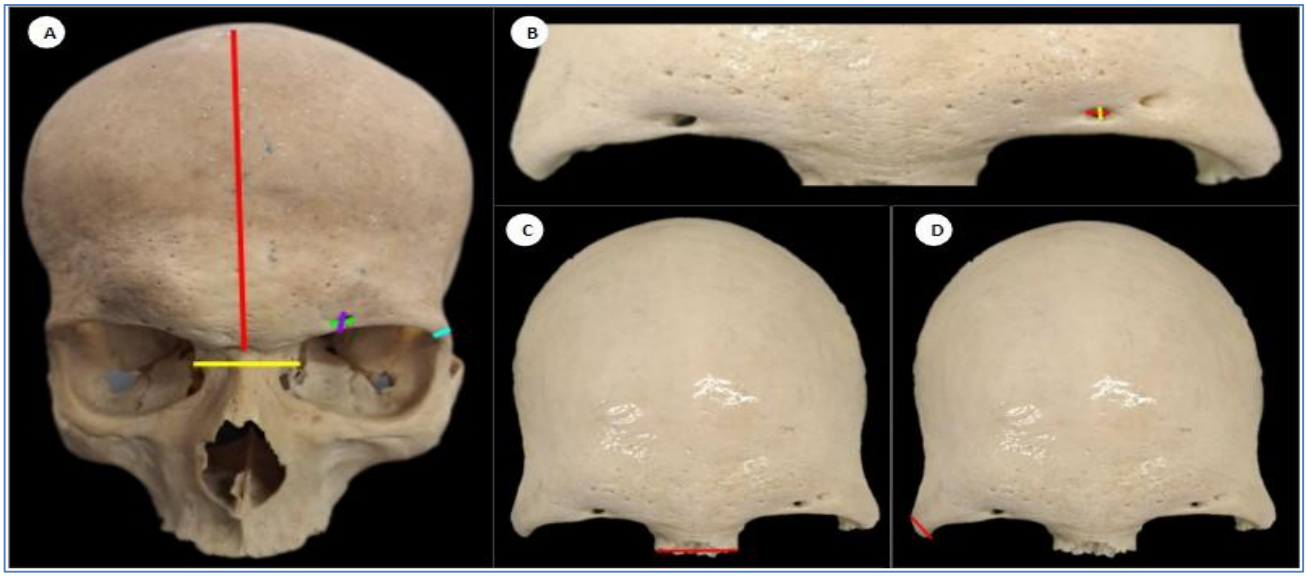

Table 1. Frontal bone morphometry results

Sample	Frontal angle (°)	Frontal length (cm)	Supraorbital foramen height (mm)		Supraorbital foramen width (mm)		Orbits distance (mm)	Zygomatic process width (mm)	
			Right	Left	Right	Left		Right	Left
ALL	90.97 ± 3.01	12.59 ± 0.61	1.85 ± 0.3	1.71 ± 0.3	3.53 ± 1.05	3.78 ± 1.31	26.64 ± 2.69	7.19 ± 1.27	7.17 ± 1.17
n	*43*	*29*	*12*	*13*	*34*	*36*	*50*	*47*	*47*
MALE	90.56 ± 2.86	12.62 ± 0.51	1.88 ± 0.28	1.73 ± 0.21	3.33 ± 0.94	3.44 ± 0.95	26.95 ± 2.86	7.58 ± 1.09	7.41 ± 1
n	*22*	*14*	*8*	*9*	*17*	*19*	*26*	*24*	*25*
FEMALE	91.40 ± 3.17	12.56 ± 0.71	1.79 ± 0.38	1.65 ± 0.48	3.72 ± 1.14	4.16 ± 1.56	26.31 ± 2.51	6.38 ± 1.75	6.89 ± 1.30
n	21	15	4	4	17	17	24	23	22

Measurements in degrees (°), centimeters (cm) and millimeters (mm).

Results are presented in **Table 1**. Data were expressed as mean ± standard deviation (SD). Student's t-test was used to compare mean values of supraorbital foramen height and width, as well as zygomatic process width, between both sides of the body; and to compare all measurements between sexes. A p-value ≤ 0.05 was considered statistically significant. Statistical analyses were performed with Jamovi Cloud, online statistical software.

3. Results

Among the analyzed frontal bones, twenty-six were classified as male bones, and twenty-four as female bones. The frontal angle was greater in females bones than in males; however, the difference was not statistically significant. Frontal length was greater in male bones, with values exceeding the overall sample mean. For supraorbital foramen height, male bones showed higher values than the sample mean, with the right side being larger than the left in both sexes. Supraorbital foramen width was greater in female bones, with values exceeding the overall sample mean. Results were not statistically significant.

The orbital distance measurement indicated that male bones had a slightly larger distance than females, the difference was not statistically significant. Males' right zygomatic process was significantly wider than the females' (p≤0.0068) while left differences were not significant.

4. Discussion

Frontal bone angle

Significant sexual dimorphism is expressed in the face upper third. Frontal bone proportions contribute to these findings with its external surface and craniometric landmarks.[9] A key measurement used to estimate sex from remaining bone was the frontal angle described by Schwalbe, which provided an accuracy rate of 75.4%.[10] To form the frontal bone inclination angle, and parallel to the Frankfurt plane, a line is placed from the craniometric point glabellae, and another line is drawn tangential to the frontal bone.[9] A threshold value of ≥ 88.6° suggests female sex, while smaller angles indicate male sex.[10] Additionally, a recent study with two hundred and eleven volume-rendered 3D cranial images, reported that this was the best frontal angle among ten, to estimate gender from the frontal bone inclination.[3]

Regarding this angle a research paper compared three different populations, sample size four-hundred-and-thirteen. A value of 78.2° or under expresses that the bones were from male, and above this angle value samples belong to females from North American and Portugal populations. However, an angle accuracy of 66% in the Chinese population, was not a satisfactory measurement on these digital 3D models.[11]Another research with seventy-seven 3D images of the Netherlands, estimated that ≤ 80.9° corresponds to male samples and ≥ 96.5° to females.[10]In the present study, the mean angle in the Colombian sample aligned more closely with female values reported in the first study, which may be related to the ethnic mix of native Colombians and migrants from the north of the continent and the European region.

Another study made in Colombia established two functional tools for sexual diagnosis: the size and the shape of the frontal region. The study relies on identifying four key anatomical points visible on seventy lateral radiographs of the glabellar region. An accuracy of 84.31% was reported.[11] Using that technique, the present results samples were classified according to their gender. When analyzed,

the frontal angle between sexes was pretty close between the used samples.

Frontal bone length

In the skull, there are external landmarks that can be important guides in several neurosurgical procedures and can lead to the measurement of the bone length. The Colombian frontal bone length values were similar to the Turkish population. One study quantified the distance between the nasion and the coronal sutures using measurements obtained from thirty dry skulls and thirty dry frontal bones.[12] A second report examined the nasion and the bregma landmark, in seventy-two dry skulls.[13] Both studies measurements were obtained with a measuring tape like in these results. The above may be due to the Christian migration of Turks to Colombia at the beginning of the nineteenth century.

Supraorbital foramen height and width

The supraorbital foramen (SOF) is a significant anatomical structure, with several digital radiography studies highlighting dimensional differences across populations, though not consistently by sex.[14] In the Thai population, gender variations in the mean horizontal widths of the SOF were found to be not significant, with an average of 2.81 ± 0.62 mm, measured with a caliper on one hundred and six dry skulls.[15] In a sample of eighty-three adult South Indian human skulls, results showed a mean height of 3.5 mm for the right SOF and 3.04 mm for the left SOF.[16] A study of the Pakistani population analyzed thirty-two dry human adult skulls, revealing that the mean height of the right side supraorbital foramen was 3.649 ± 0.687 mm, while the left side foramen measured 3.489 ± 0.651 mm.[14] On the other hand, males a study conducted in Southeast Europe on sixty dry skulls indicates that males exhibit higher values of SOF dimensions compared to females. The measurements for SOF width were 3.75 ± 1.36 mm in males and 3.58 ± 1.04 mm in females, while the SOF height was 1.98 ± 0.76 mm in males and 1.83 ± 0.73 mm in females. Additionally, on the right side they obtained results of 2.09 ± 0.74 mm for height and 3.66 ± 1.44 mm for width, indicating that these were higher values compared to the left side, which had a height of 1.89 ± 0.64 mm and a width of 3.63 ± 1.25 mm.[17]

As for the Colombian sample, the SOF exhibited a mean width of 3.65 ± 1.18 mm which is a higher value than the first and second Thai studies. Regarding the laterality, the Colombian samples on both sides were smaller than SOF dimensions made in India, and similar to the Southeast Europe population. In relation to this last study the male SOF width was higher than the Colombian sample 3.29 ± 0.9 mm, and the female width was lower than the ones in the present results, 3.94 ± 1.35 mm. Regarding SOF height, the Colombian samples showed lower values than those reported in South Indian and Pakistani studies, and a similar result than the Indian mean and the Southeast Europe population mean by laterality. This last study revealed that according to the gender, the Colombian sample displayed similar results, being 1.8 ± 0.24 mm for male and 1.72 ± 0.43 mm for female. The similarity of results between the Southeastern Europe population and the Colombian population could be due to the European ancestry that was present in the colonization of the South American country.

Orbits distance

Morphological variations of the orbital width can be used in forensic medicine to determine sex or ethnicity. Comparing the Colombian sample with an Indian study used the radiographs of fifty males and fifty-one females. It showed similar male results and lower female results.[18] A Thailand investigation and a second Indian paper showed lower male and female results. The Turkish population with a paper on sixty skulls of unknown gender, also exhibited a lower mean than the Colombian sample, while the Canadian skulls displayed a similar result. The latter could be due to migration within the American continent.[19]

Zygomatic frontal process width

The Colombian zygomatic frontal process width values were similar to an European country population. These results were recorded in a Bulgarian study on one hundred and twenty-five dry skulls.[20] However, no further studies were found to compare this measurement with other populations, which leaves no room for conjecture.

5. Conclusion

Frontal bone craniometry provides valuable insights for multiple disciplines, including anatomy and forensic science. This study established a standardized protocol for measuring the frontal bone in dry skulls, emphasizing angular and linear parameters for sex estimation and morphometric analysis. Findings were consistent with results from European and North American male populations, highlighting morphological similarities with Colombian remains and contrasts with South Asian skulls across specific dimensions.

6. Recommendations / suggestions

Future studies should include a larger sample size, including bones from other ethnicities and continents such as Oceania, Central America, and Africa. This would enhance the contrast and analysis of the results and allow a more comprehensive bone variation understanding. The bones for this study were obtained from the University Laboratory which might be from donors in the Andean region of the country. Integration with radiological studies and 3D imaging is recommended for future comparative research.

Ethical Clearance: IEC approval is taken from the Institutional Ethical committee.

Contributor ship of Author: All authors equally contributed.

Conflict of interest: None to declare.

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