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The Casado (2017) method for sex estimation of contemporary brazilian skulls: a validation study

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Casado (2017) described a low-cost and practical method for sex estimation of adult skulls using precision calipers to evaluate anatomical landmarks. **Aim:** This study aimed to validate this method in Brazilian skulls. **Methods:** Measurements of 202 skulls (118 male and 84 female) were collected, according to Casado (2017). **Results:** The results were very promising. Except for the external occipital protuberance, the anatomical landmarks were related to sex ($p < 0.0001$). The anatomical landmarks from both sexes were included, and 72.16% of the skulls were correctly classified. The individual percentage per sex was similar, with 71.40% accuracy in male skulls and 72.92% in female skulls. **Conclusion:** The method efficiently identified sex differences in anatomical landmarks of Brazilian skulls regardless of age and ancestry.

Keywords: Forensic sciences. Craniometry. Forensic anthropology. Skull. Sex differences.

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Introduction

The worldwide population increased from one to six billion over the past 200 years, especially in urban areas. The number of deaths caused by diseases, natural disasters, and violent crimes also increased, highlighting the importance of person identification using their bones[1].

Currently Brazil has over 210 million inhabitants and high miscegenation, which provides heterogeneous characteristics in the population, hindering forensic anthropology[2,3]. Miscegenation provided heterogeneous characteristics in the Brazilian population, making forensic anthropology challenging in this population[3]. Moreover, studies indicate secular skull changes in other populations[4-8] however, whether these changes affected the Brazilian population is unclear.

The efficacy of sex estimation using only anatomical landmarks is not a consensus[9]. However, the skull is considered one of the best tools for sex estimation in the lack of pelvic or postcranial elements. The skull is resistant to adverse conditions and can be easily submitted to quantitative evaluations[3,10-12]. In addition, the best way to achieve efficient sex estimation is by using many variables[13-15].

The usual method to identify sex from adult skulls comprises a quantitative or visual analysis of skeletal traits using an ordinal scale; its accuracy relies on a trained evaluator. Imaging tests are also widely used to study sexual dimorphism with high accuracy[16-18]. However, the high-cost equipment hinders access in many forensic analysis institutes[19,20].

Simple, low-cost, and accessible techniques (e.g., precision calipers) for sex estimation that requires little training have demonstrated high reliability[21]. Casado[11] (2017) proposed a low-cost and easy-to-replicate method using precision calipers compared with computed tomography. In Brazil, low-cost methods for sex estimation are important due to the miscegenation and varied socioeconomic characteristics between regions. Therefore, this study aimed to test and validate the method proposed by Casado[11] to identify sexual dimorphism in Brazilian skulls.

Materials and Methods

This cross-sectional study was conducted at the Skull Museum of the Federal University of São Paulo, Brazil. Ethical approval was obtained from the University's Ethics and Research Committee (no.: 3.035.353/2018).

Sample

Dry adult skulls with complete biological profiles (sex, age, and ancestry) were included. Those with fragmentation or trauma that hindered or could alter the measurements were excluded. From the original sample (n = 403), only 202 skulls (118 male and 84 women) were selected for analysis (Table 1).

Table 1. Biological characteristics of the sample.

Sex	Frequency	%
Male	118	58.42
Female	84	41.58
Total	202	100.00
Age	**Mean**	**SD**
Male	42.95	12.75
Female	40.75	16.33
Total	42.05	14.32
Ancestry	**Frequency**	**%**
White	90	44.55
Black	112	55.45
Total	202	100.00

SD = Standard deviation.

The skulls were from deaths documented between 1933 and 1970, representing changes in a modern population[4-6,8,22].

A precision compass (Mitutoyo®, São Paulo, Brazil) was used to measure the linear distances between the anatomical landmarks to determine the external projection of each trace. A digital depth caliper (Digimess®, São Paulo, Brazil) was used to measure the depth of bony protuberances and capture the three-dimensional nature of an anatomical landmark[11].

Procedures

Twelve measurements were performed on six anatomical landmarks: three sites of muscle attachment (external occipital protuberance, nuchal protuberance [right {R}, left {L}, and center], and mastoid process [R and L]) and three anatomical landmarks evaluated due to hormonal differences (glabella, supraorbital ridge [R and L], and frontal boss [R, L, and center])[11]. The skulls were fixed on specific support, and one evaluator performed all measurements. For each measurement, the evaluator moved the depth compass (i.e., the central arm) to find the most protruding point of each anatomical landmark to determine the external projection. The measurements were systematized and followed the order described in Table 2.

Table 2. Anatomical landmarks.

Anterior View
From point A to point B (Casado, 2017)
1R - Right supraorbital ridge
1L - Left supraorbital ridge
2 - Glabella

Continue

Continuation

From bregma to frontomalare temporale
3R - Right frontal boss
3L - Left frontal boss
From bregma to nasion
3C - Central frontal boss
Posterior View
From lambda to opisthion
4 - External occipital protuberance
From lambda to mastoid process groove
5R - Right nuchal protuberance
5L - Left nuchal protuberance
From inion to opisthion
5C - Central nuchal protuberance
Lateral View
From external auditory meatus to mastoid process groove
6R - Right mastoid process
6L - Left mastoid process

Statistical analysis

The Shapiro-Wilk test analyzed the data distribution. The Mann-Whitney verified the relationship between sex and skull anatomical landmarks measurements. The multivariate analysis using discriminant functions was applied to find which group the skulls belonged to (0 = male; 1 = female). The Chi-square test analyzed the association between the results and the expected distribution. The analyses were performed in GraphPad Prism®, and the significance was set at $p < 0.05$.

To set the cut-off point for sex estimation accuracy, we considered the mean, standard deviation, and value range of each sex. The cut-off point was used to estimate the sex for each measurement. Then, the estimative was divided by the correct number of skulls from each sex. The same calculus was made for the overall classification.

Results

The sample was not normally distributed. Except for the external occipital protuberance, the anatomical landmarks were related to sex (Table 3, Figure 1).

Table 3. Descriptive statistics by anatomical landmarks.

	Male (n = 118)				**Female (n = 84)**			
	Mean	**SE**	**W**	**R**	**Mean**	**SE**	**W**	**R**
Right supraorbital ridge	21.11 ± 3.26	0.2981	0.898	< 0.0001	25.46 ± 3.77	0.406	0.823	< 0.0001
Left supraorbital ridge	21.56 ± 3.4	0.3108	0.900	< 0.0001	26.37 ± 3.8	0.410	0.807	< 0.0001

Continue

Continuation

Glabella	20.86 ± 3.53	0.3225	0.899	< 0.0001	23.07 ± 3.52	0.379	0.845	< 0.0001
Right frontal boss	22.19 ± 3.36	0.307	0.897	< 0.0001	22.74 ± 3.59	0.387	0.854	< 0.0001
Left frontal boss	23.12 ± 3.57	0.3258	0.864	< 0.0001	23.62 ± 3.63	0.392	0.762	< 0.0001
Central frontal boss	13.91 ± 3.06	0.2796	0.976	0.0311	14.42 ± 3.06	0.330	0.971	0.0498
External occipital protuberance	12.52 ± 3.73	0.3405	0.986	0.2618	14.93 ± 3.82	0.412	0.987	0.5127
Right nuchal protuberance	20.70 ± 3.45	0.3154	0.934	< 0.0001	22.08 ± 3.8	0.410	0.889	< 0.0001
Left nuchal protuberance	20.58 ± 3.63	0.3319	0.955	0.0006	21.46 ± 3.59	0.388	0.901	< 0.0001
Central nuchal protuberance	36.60 ± 4.11	0.3754	0.604	< 0.0001	36.53 ± 4.22	0.455	0.459	< 0.0001
Right mastoid process	29.98 ± 3.3	0.3009	0.624	< 0.0001	30.94 ± 3.59	0.387	0.477	< 0.0001
Left mastoid process	30.16 ± 3.29	0.3004	0.620	< 0.0001	31.43 ± 3.68	0.397	0.498	< 0.0001

Mean ± standard deviation in millimiters; SE = standard error; W = Shapiro-Wilk (alpha = 0.05); R = Mann-Whitney (p < 0.05).

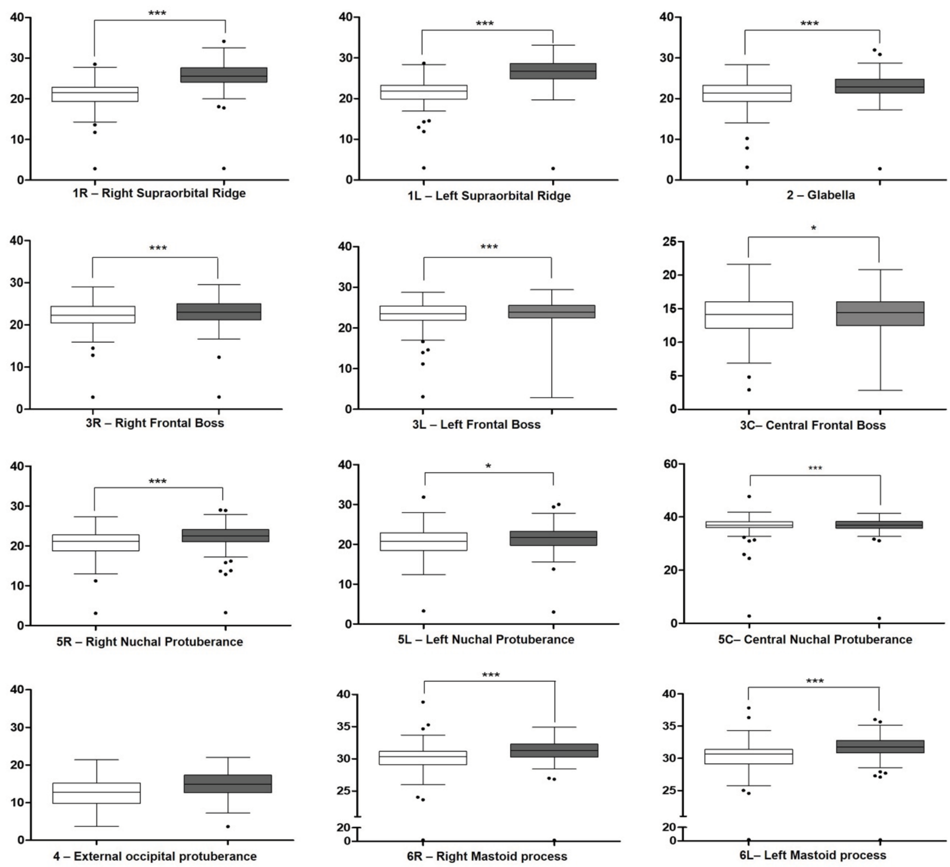

Figure 1. Boxplot of Shapiro-Wilk distribution. White boxes represent male skulls and gray boxes represent female skulls. ***p < 0.001; *p < 0.05.

The measures differed between the sexes (p=0.0009), showing that the method effectively identified a sexual dimorphism in the skulls (Table 4).

Table 4. Chi-square test comparing male and female skulls.

Function test	Chi-square	df	*P*
1	10.96	1	0.0009

In the general classification, we found an overall accuracy of 72.16%, including all anatomical landmarks. Moreover, the accuracy in each group was similar (71.40% accuracy in male and 72.92% in female skulls) (Table 5).

Table 5. Overall classification of the skulls. The numbers in bold indicate the percentage of correct identification of each sex.

	Planned participation in the group		
	Male	**Female**	**Total**
Original count			
Male	61	57	118
Female	23	61	84
%			
Male	71.40	28.6	100
Female	27.08	72.92	100

72.16% of the original cases grouped were correctly classified.

The accuracy values were separated by anatomical landmark and sex (Table 6); values varied between 64.30% and 82.20%. The anatomical landmarks that least identified the sexual dimorphism were the external occipital protuberance on male skulls (66.10%) and the left supraorbital ridge on female skulls (64.30%). Additionally, the ones that most identified it were the central nuchal protuberance (82.20%) on male skulls and the left frontal boss (82.10%) on female skulls.

Table 6. Percentage of correct identification by variable.

	Male (n = 118)	Female (n = 84)
1R - Right supraorbital ridge	68.6	75.0
1L - Left supraorbital ridge	76.3	64.3*
2 - Glabella	72.0	71.4
3R - Right frontal boss	69.5	70.2
3L - Left frontal boss	71.2	82.1**

Continue

Continuation

3C - Central frontal boss	72.0	66.7
4 - External occipital protuberance	66.1*	70.2
5R - Right nuchal protuberance	67.8	75.0
5L - Left nuchal protuberance	72.0	75.0
5C - Central nuchal protuberance	82.2**	75.0
6R - Right mastoid process	70.3	72.6
6L - Left mastoid process	68.6	77.4

* Lower accuracy; ** Higher accuracy.

Discussion

Although studies indicated secular changes in the skulls[4-8], whether they affected the sexual dimorphism in Brazilian skulls is unclear. The evaluated adult skulls were similar to those analyzed by Casado[11] (2017). However, our sample included skulls from mixed-race people due to the miscegenation of the Brazilian population from immigration or migratory movements[2,3]. Thus, validating a method in Brazilian skulls must consider every ethnic group.

Although Brazilians have varied ethnic groups, their skulls exhibit similar sexual dimorphism. Studies stated that most differences exist within geographic populations, not between them[23-25]. However, Brazilian forensic anthropologists suggested that bones must be analyzed in each population to identify sexual differences, considering the notorious level of variation and miscegenation of contemporary human beings[1,3,12,26].

The methods used to determine the external projection of anatomical landmarks can be subjective or objective. Subjective methods, such as visual inspection, relies on an experienced evaluator, taking time and being costly. Objective methods use measurements to quantify the anatomical landmarks and compare intra- and inter-populations. In the latter, the geometric analysis of photographs and imaging tests depend on specific software, computers, and specialized evaluators. Imaging tests are high-priced and far from reality in most forensic institutes.

In this study, the depth caliper measured and captured the three-dimensional nature of the anatomical landmarks of the skulls. Our results showed that using calipers is simple and effective and achieves values similar to traditional methods (visual inspection or imaging) in adult skulls, they are affordable, easy, and do not require specific training or long-time experience, making their use accessible to identify sexual dimorphism[3,12,21,26-28]. Although some studies separated the skulls into ethnic groups, this study considered all skulls as a single group.

In this study, the sex estimation accuracy was similar to the values found by Casado[11] (2017) (71.4% *versus* 69.6% for men; 72.9% *versus* 74.7% for women, respectively). The overall classification (72.20%) was also the same as presented by Casado[11] (2017), suggesting high accuracy and reliability of the method. Walker[25] (2008) obtained similar results using visual inspection (78% accuracy for Native Americans and between 84% and 88% for Non-natives). In addition, Garvin et al.[29] (2014) reported 82% accuracy for the overall sample and between 63% and 79% for each group, Krüger et al.[30] (2015) found between 68% and 84% in the overall sample (without considering ancestry), and Godde et al.[31] (2018) 80% accuracy in the overall sample.

Another method for sex estimation is the analysis of the geometry of anatomical landmarks in photographs. Nikita and Michopoulou[13] (2018) reported accuracy of 85.10% and 94.60% in identifying male and female skulls, respectively. Also, Nikita[32] (2019) reported 87% accuracy for the overall sample. Both studies used Greek skulls, a population with little miscegenation, possibly justifying the high accuracy. González-Colmenares et al.[33] (2019) used the same technique in radiographs of Colombian skulls and found 88.60% accuracy. Other authors performed the same technique using computed tomography: Kimmerle et al.[16] (2008) reported 77.80% accuracy; Bulut et al.[34] (2016), 77.50%; and Čechová et al.[35] (2021), 72.80%. All values were similar to ours (72.20%), suggesting the reliability of our results and allowing method comparison.

Petaros et al.[15] (2021), examined the volume of mastoid processes in Medieval Croatian skulls using visual inspection, precision calipers, and geometric analysis and obtained 67.1%, 69.4%, and 81.0% accuracy, respectively. This study was relevant to understand the contribution of each method. The more qualitative and quantitative information we can extract from the skulls, the greater the identification accuracy, greater population specificity susceptible to secular changes, and lesser challenge in the judicial sphere once judicial precedents require accurate and quantifiable methods to be presented in forensic testimony[12]. Therefore, we believe that the method proposed by Casado[11] (2017) has high admissibility in court.

In conclusion, although the method proposed by Casado was developed for American skulls, we found similar measure values in Brazilian skulls. Moreover, the method efficiently classified the sexual dimorphism of Brazilian skulls, regardless of age and ancestry.

Ethical Approval

The research protocol was submitted for evaluation and approved by the Ethical Committee of the Federal University of São Paulo São Paulo, Brazil (nº 3.035.353/2018). The stages of the study were carried out according to the approved guidelines.

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Declaration of Interest

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Data availability

Datasets related to this article will be available to the corresponding author upon request.

Author Contribution

Silvio Antonio Garbelotti Junior: project conception and design, drafting the article, analysis and interpretation of data, final approval of the version to be published**.** **Rodrigo Barbosa de Souza:** analysis and interpretation of data, statistical analysis, final approval of the version to be published. **Marco Antonio de Angelis:** critical review of content, final approval of the version to be published. **Sérgio Ricardo Marques:** critical review of content, drafting the article, final approval of the version to be published. **Ricardo Luiz Smith:** project conception and design, analysis and interpretation of data, critical review of content, final approval of the version to be published**.** All authors actively revised and approved the final version of the manuscript.

References

1. Mello-Gentil T, Souza-Mello V. Contributions of anatomy to forensic sex estimation: focus on head and neck bones. Forensic Sci Res. 2021 Jul;7(1):11-23. doi: 10.1080/20961790.2021.1889136.
2. Cunha E, Lopez-Capp TT, Inojosa R, Marques SR, Moraes LOC, Liberti E, et al. The Brazilian identified human osteological collections. Forensic Sci Int. 2018 Aug;289:449.e1-449.e6. doi: 10.1016/j.forsciint.2018.05.040.
3. Gomes SL, Cardozo AFC, Cavalcante DFB, Daruge Júnior E, Ulbricht V, Pereira Neto JS, et al. Sex determination by means of linear measurements and skull areas of brazilian adults. Rev Bras Odontol Leg 2020;7(3):87-96.
4. Jantz RL, Meadows Jantz L. Secular change in craniofacial morphology. Am J Hum Biol. 2000 May;12(3):327-38. doi: 10.1002/(SICI)1520-6300(200005/06)12:3<327::AID-AJHB3>3.0.CO;2-1.
5. Malina RM, Peña Reyes ME, Tan SK, Buschang PH, Little BB, Koziel S. Secular change in height, sitting height and leg length in rural Oaxaca, southern Mexico: 1968-2000. Ann Hum Biol. 2004 Nov-Dec;31(6):615-33. doi: 10.1080/03014460400018077.
6. Cridlin, S. An investigation of secular change in the craniofacial morphology of white and black males and females in the United States. In: American Journal of Physical Anthropology. New York: John Wiley & Sons; 2006. p.79.
7. Weisensee KE, Jantz RL. Secular changes in craniofacial morphology of the Portuguese using geometric morphometrics. Am J Phys Anthropol. 2011 Aug;145(4):548-59. doi: 10.1002/ajpa.21531.
8. Spradley K, Stull KE, Hefner JT. Craniofacial secular change in recent mexican migrants. Hum Biol. 2016 Jan;88(1):15-29. doi: 10.13110/humanbiology.88.1.0015.
9. Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci. 2011 Mar;56(2):289-96. doi: 10.1111/j.1556-4029.2010.01635.x.
10. Gupta AD, Banerjee A, Kumar A, Rao SR, Jose J. Discriminant function analysis of mastoid measurements in sex determination. J Life Sci 2012;4(1):1-5.
11. Casado AM. Quantifying sexual dimorphism in the human cranium: a preliminary analysis of a novel method. J Forensic Sci. 2017 Sep;62(5):1259-65. doi: 10.1111/1556-4029.13441.

12. Sassi C, Picapedra A, Álvarez-Vaz R, Martins Schmidt C, Ulbricht V, Daruge Júnior E, et al. Sex determination in a Brazilian sample from cranial morphometric parameters - a preliminary study. J Forensic Odontostomatol. 2020 May;38(1):8-17.

13. Nikita E, Michopoulou E. A quantitative approach for sex estimation based on cranial morphology. Am J Phys Anthropol. 2018 Mar;165(3):507-17. doi: 10.1002/ajpa.23376. Epub 2017 Dec 19.

14. Sinhorini PA, Costa IAP, Lopez-Capp TT, Biazevic MGH, de Paiva LAS. Comparative analysis of four morphometric methods for sex estimation: A study conducted on human skulls. Leg Med (Tokyo). 2019 Jul;39:29-34. doi: 10.1016/j.legalmed.2019.06.001.

15. Petaros A, Sholts SB, Čavka M, Šlaus M, Wärmländer SKTS. Sexual dimorphism in mastoid process volumes measured from 3D models of dry crania from mediaeval Croatia. Homo. 2021 Jun 25;72(2):113-27. doi: 10.1127/homo/2021/1243.

16. Kimmerle EH, Ross A, Slice D. Sexual dimorphism in America: geometric morphometric analysis of the craniofacial region. J Forensic Sci. 2008 Jan;53(1):54-7. doi: 10.1111/j.1556-4029.2007.00627.x.

17. Petaros A, Garvin HM, Sholts SB, Schlager S, Wärmländer SKTS. Sexual dimorphism and regional variation in human frontal bone inclination measured via digital 3D models. Leg Med (Tokyo). 2017 Nov;29:53-61. doi: 10.1016/j.legalmed.2017.10.001.

18. Zhang Y, Schepartz LA. Three-dimensional geometric morphometric studies of modern human occipital variation. PLoS One. 2021 Jan;16(1):e0245445. doi: 10.1371/journal.pone.0245445.

19. Garvin HM, Ruff CB. Sexual dimorphism in skeletal browridge and chin morphologies determined using a new quantitative method. Am J Phys Anthropol. 2012 Apr;147(4):661-70. doi: 10.1002/ajpa.22036.

20. Lee M, Gerdau-Radonic K. Variation within physical and digital craniometrics. Forensic Sci Int. 2020 Jan;306:110092. doi: 10.1016/j.forsciint.2019.110092. Epub 2019 Nov 29.

21. Banerjee R. Commentary on: Casado AM. Quantifying sexual dimorphism in the human cranium: a preliminary analysis of a novel method. J Forensic Sci 2017;62(5):1259-65. J Forensic Sci. 2018 Nov;63(6):1932. doi: 10.1111/1556-4029.13910.

22. Jellinghaus K, Hoeland K, Hachmann C, Prescher A, Bohnert M, Jantz R. Cranial secular change from the nineteenth to the twentieth century in modern German individuals compared to modern Euro-American individuals. Int J Legal Med. 2018 Sep;132(5):1477-84. doi: 10.1007/s00414-018-1809-5.

23. Andreasen RO. A new perspective on the race debate. Br J Philos Sci 1998;49(2):199-225.

24. Roseman CC, Weaver TD. Multivariate apportionment of global human craniometric diversity. Am J Phys Anthropol. 2004 Nov;125(3):257-63. doi: 10.1002/ajpa.10424.

25. Walker PL. Sexing skulls using discriminant function analysis of visually assessed traits. Am J Phys Anthropol. 2008 May;136(1):39-50. doi: 10.1002/ajpa.20776.

26. Leal MDOCD, Daruge Júnior E, Francesquini Júnior L, Costa ST, Delwing F, Jara Espejo MA, et al. Estimation of sex in Brazilian samples with cross-validation in populations of different regions. Forensic Sci Int: Rep. 2019 Nov;1:100030. doi: 10.1016/j.fsir.2019.100030.

27. Fortes de Oliveira O, Lima Ribeiro Tinoco R, Daruge Júnior E, Silveira Dias Terada AS, Alves da Silva RH, Paranhos LR. Sexual dimorphism in Brazilian human skulls: discriminant function analysis. J Forensic Odontostomatol. 2012 Dec;30(2):26-33.

28. Ulbricht V, Schmidt CM, Groppo FC, Daruge Júnior E, Queluz DP, Francesquini Júnior L. Sex estimation in brazilian sample: qualitative or quantitative methodology? Braz J Oral Sci 2017;16:e17047. doi: 10.20396/bjos.v16i0.8650495.

29. Garvin HM, Sholts SB, Mosca LA. Sexual dimorphism in human cranial trait scores: effects of population, age, and body size. Am J Phys Anthropol. 2014 Jun;154(2):259-69. doi: 10.1002/ajpa.22502.

30. Krüger GC, L'Abbé EN, Stull KE, Kenyhercz MW. Sexual dimorphism in cranial morphology among modern South Africans. Int J Legal Med. 2015 Jul;129(4):869-75. doi: 10.1007/s00414-014-1111-0. Epub 2014 Nov 14.

31. Godde K, Thompson MM, Hens SM. Sex estimation from cranial morphological traits: use of the methods across American Indians, modern North Americans, and ancient Egyptians. Homo. 2018 Sep;69(5):237-7. doi: 10.1016/j.jchb.2018.09.003.

32. Nikita E. Quantitative sex estimation based on cranial traits using r functions. J Forensic Sci. 2019 Jan;64(1):175-80. doi: 10.1111/1556-4029.13833. Epub 2018 Jun 1.

33. González-Colmenares G, Sanabria Medina C, Rojas-Sánchez MP, León K, Malpud A. Sex estimation from skull base radiographs in a contemporary Colombian population. J Forensic Leg Med. 2019 Feb;62:77-81. doi: 10.1016/j.jflm.2019.01.006.

34. Bulut O, Petaros A, Hizliol İ, Wärmländer SK, Hekimoglu B. Sexual dimorphism in frontal bone roundness quantified by a novel 3D-based and landmark-free method. Forensic Sci Int. 2016 Apr;261:162.e1-5. doi: 10.1016/j.forsciint.2016.01.028.

35. Čechová M, Dupej J, Brůžek J, Bejdová Š, Velemínská J. A test of the Bulut et al. (2016) landmark-free method of quantifying sex differences in frontal bone roundness in a contemporary Czech sample. J Forensic Sci. 2021 Mar;66(2):694-9. doi: 10.1111/1556-4029.14603. Epub 2020 Oct 26.