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The applicability of the Baudoin Index for sex estimation in Brazilian skulls

A aplicabilidade do Índice Baudoin para estimativa de sexo em crânios Brasileiros

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ABSTRACT
Introduction: The Baudoin Index (BI) is a human identification method for sex estimation based on occipital condyle measures. Objective: To investigate the applicability of the BI for sex estimation in a Brazilian sample. Material and Method: This was a blind cross-sectional study with 209 skulls from the Center for Studies in Forensic Anthropology, Pernambuco School of Dentistry, University of Pernambuco (CEAF / FOP / UPE). The right and left occipital condyles were measured for width and length using a digital caliper. Subsequently, the BI formula was applied to the measurements for classification of sex. The data were analyzed descriptively and by Student's *t* test, Mann Whitney test, and Pearson's Chi square, considering a 5% significance level. Results: The occipital condyle measures showed significant sex-related differences ($P < 0.05$), except for the width of the right occipital condyle ($P = 0.376$). The agreement rates of the BI in males (38%, right side; 29.6%, left side) were lower than those in females (59.4%, right side; 52.5%, left side). Conclusion: The Baudoin Index did not show accurate sex estimates in the Brazilian sample of skulls analyzed herein. Thus, this index is not suitable for estimating sex in this population.

Keywords: Forensic Anthropology, Forensic Dentistry, Skull, Skull Base, Sex.

RESUMO
Introdução: O Índice Baudoin (IB) é um método de identificação humana para estimativa do sexo baseado em medidas do côndilo occipital. Objetivo: Investigar a aplicabilidade do IB para estimativa de sexo em uma amostra brasileira. Material e Método: Estudo transversal cego com 209 crânios do Centro de Estudos em Antropologia Forense da Faculdade de Odontologia de Pernambuco da Universidade de Pernambuco (CEAF / FOP / UPE). Os côndilos occipitais direito e esquerdo foram medidos quanto à largura e comprimento usando um paquímetro digital. Posteriormente, a fórmula do BI foi aplicada às medidas para classificação do sexo. Os dados foram analisados descritivamente e pelos testes t de Student, Mann Whitney e Qui quadrado de Pearson, considerando um nível de significância de 5%. Resultados: As medidas do côndilo occipital mostraram diferenças significativas em relação ao sexo (P <0,05), exceto para a largura do côndilo occipital direito (P = 0,376). As taxas de concordância do IB no sexo masculino (38% lado direito; 29,6% lado esquerdo) foram menores que no feminino (59,4% lado direito; 52,5% lado esquerdo). Conclusão: O Índice Baudoin não mostrou estimativas precisas de sexo na amostra brasileira de crânios aqui analisada. Portanto, esse índice não é adequado para estimar o sexo nesta população.

Palavras-chave: Antropologia Forense, Odontologia Legal, Crânio, Base do crânio, Sexo.

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1 INTRODUCTION

Estimating sex in complete bones is a relatively straightforward process in forensic sciences, with the pelvis being the human bone with the greatest sexual dimorphism. Nevertheless, there are circumstances in which a whole skeleton is not available. In these situations, the skull plays a fundamental role in the determination of sex[6].

In 1962, Krogman[7] pointed out that the pelvis and skull are the main determining elements of sex in humans. The author classified the percent degree of sexual dimorphism of each of these structures individually (95% and 92%, respectively) and combined (98%) as compared to the examination of the whole skeleton (100%). Among fourteen dimorphic cranial parameters described by the author, the morphological analysis of occipital condyles revealed greater dimensions in males compared to females[7].

Over the centuries, men have acquired a stronger musculature than women, so that their bones were shaped following muscle insertions into more robust and protuberant structures[6]. Therefore, female skulls are qualitatively more delicate, with a more vertical forehead, sharp supraorbital edges, underdeveloped mastoid processes, short and wide occipital condyles, less robust mandible, and less pronounced muscle insertions. In contrast, male skulls have a forehead leaning backwards, with blunt supraorbital edges, prominent mastoid apophyses, long and narrow occipital condyles, robust mandible, and more pronounced crests of muscle insertions[8,9].

The Baudoin Index (BI) has been proposed for the estimation of human sex through a mathematical formula using the widths and lengths of the occipital condyles. Based on a quantitative outcome, sex is then classified as male, female or unclear, according to a pre-established table[9]. In this study, we investigated the applicability of the BI for sex estimation in a Brazilian sample of cataloged skulls.

2 MATERIAL AND METHODS

This study was previously approved by the Research Ethics Committee of the Center for Health Sciences at the Federal University of Paraíba, under protocol CAAE no. 67397417.0.1001.5188 (Appendix A). The procedures were carried out in compliance with the National Health Council's Resolution no. 466, of December 12, 2012, which regulates research involving human beings.

This was a blind cross-sectional study with a universe of 239 skeletons from the Center for Studies in Forensic Anthropology, Pernambuco School of Dentistry, University of Pernambuco (CEAF / FOP / UPE), which had been previously cataloged regarding sex, and age at death. Skeletons lacking skulls or with cranial structures affected by severe anomalies and / or fractures

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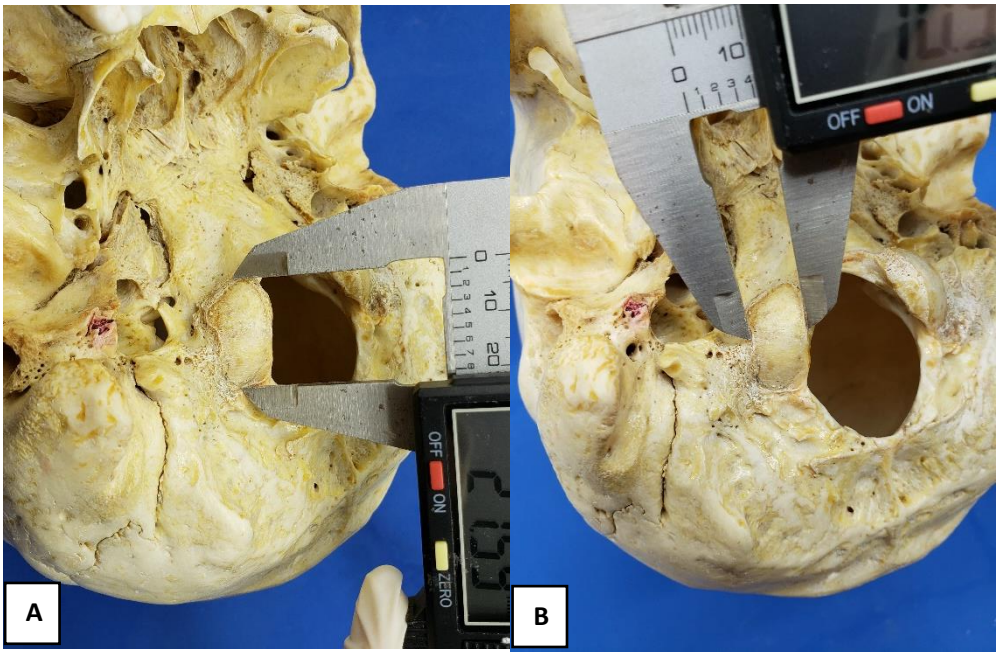
that prevented the measurement of the occipital condyle(s), were excluded from the analysis. The final sample consisted of 209 human skulls.

As shown in Figure 1, a Stainless-Hardened® digital caliper (150 mm) was used to perform four measurements: width and length of the occipital condyles on the right and left sides. At the end of each measurement, the caliper was zeroed to avoid possible variations and measuring biases.

Figure 1. Occipital condyle measurements (A- width, B- length) on the right and left sides for estimation of sex by the Baudoin Index.



A pilot study was previously carried out with 20 skulls from the same bone collection for calibration of the examiner to the study criteria. Each skull was measured by the same examiner, within a 7-day interval in between the first and second analysis, for determination of the agreement rate. The Kappa statistical test showed a satisfactory agreement between the measurements (≥ 0.92), indicating adequate training of the examiner in relation to the study criteria. As no adjustments to the pilot study were necessary, the twenty skulls used for calibration purposes were also included in the final sample ($n = 209$).

The relationship between the maximum width and length of the occipital condyle was used to calculate the BI, with the final value multiplied by 100. According to the reference table proposed by the BI, a value of 55 is indicative of a female skull; between 50 and 55, unclear estimate, whereas a value below 50 is indicative of a male skull[8].

The data were analyzed descriptively for sex distribution in the sample and showed a normal distribution curve. Pairwise comparisons were carried out using Student's *t* and Mann-Whitney tests. The correlation between the actual (cataloged) sex and the BI estimate was determined by

Pearson's Chi Square. All statistical tests were carried out in the Statistical Package for Social Science program (SPSS® Professional Statistics, version 22.0), considering a 5% significance level.

3 RESULTS

Of the 209 skulls analyzed, 108 were from males and 101 from females. As shown in Table 1, the occipital condyle measurements were statistically different according to sex ($P < 0.05$), except for the width of the right occipital condyle ($P = 0.376$). Overall, the means of the measurements were higher in males than females.

Table 1. Measurements of the right and left occipital condyles according to sex in skulls from the Center for Studies in Forensic Anthropology (FOP / UPE), 2018.

Parameter	Sex	*n*	Minimum value	Maximum value	Mean	Standard-deviation	*P*-value
Width of the right occipital condyle	Male	108	6.04	17.28	12.30	2.18	$P^{(1)} = 0.376$
	Female	101	8.60	18.53	12.06	1.72	
Length of the right occipital condyle	Male	108	10.59	30.20	23.27	2.82	$P^{(1)} = 0.000$*
	Female	101	15.78	27.70	21.24	2.25	
Width of the left occipital condyle	Male	108	8.10	18.22	12.66	1.96	$P^{(2)} = 0.002$*
	Female	101	8.39	20.13	11.91	1.78	
Length of the left occipital condyle	Male	108	10.09	27.44	22.75	2.83	$P^{(1)} = 0.000$*
	Female	101	15.57	28.28	21.15	2.57	

(1) Student's *t* test.
(2) Mann-Whitney test.
(*) Significance level at 5%.

The BI estimates indicated that only the right occipital condyle measurements were statistically different according to sex ($P < 0.05$) (Table 2).

Table 2. Right- and left-side Baudoin Index values according to sex in skulls from the Center for Studies in Forensic Anthropology (FOP / UPE), 2018.

Parameter	Sex	*n*	Minimum value	Maximum value	Mean	Standard-deviation	*P*-value
Right-side BI value	Male	108	29.03	90.61	53.72	11.76	$P^{(1)} = 0.017$*
	Female	101	33.21	90.72	57.37	9.89	
Left-side BI value	Male	108	35.76	99.34	56.20	11.40	$P^{(2)} = 0.485$
	Female	101	35.44	88.16	57.19	11.16	

(1) Student's *t* test.
(2) Mann-Whitney test.
(*) Significance level at 5%.

The correlations between sex estimates according to the BI and the actual (cataloged) sex of the skull were determined by Pearson's Chi-Square test. The analysis of the right-side BI indicated an agreement of 38.0% for males and 59.4% for females. Furthermore, 14.8% and 16.8% of the skulls cataloged as male and female, respectively, were classified by the BI as unclear ($P > 0.05$) (Table 3).

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Table 3. Frequency and percent agreement between the Baudoin Index estimate and the actual (cataloged) sex based on right occipital condyle measurements in skulls from the Center for Studies in Forensic Anthropology (FOP / UPE), 2018.

Baudoin Index – Right Occipital Condyle						
		Male *n* %	Female *n* %	Unclear *n* %	TOTAL	P-value
Cataloged sex	Male	41 (38.0)	51 (47.2)	16 (14.8)	108 (100.0)	
	Female	24 (23.8)	60 (59.4)	17 (16.8)	101 (100.0)	$P^{(1)} = 0.083$
	TOTAL	65 (31.1)	111 (53.1)	33 (15.8)	209 (100.0)	

(1) Pearson's Chi Square test.

The analysis of the left-side BI indicated an agreement of 29.6% for males and 52.5% for females. Furthermore, 17.6% and 20.8% of the skulls cataloged as male and female, respectively, were classified by the BI as unclear ($P > 0.05$), accepting the null hypothesis (Table 4).

Table 4. Frequency and percent agreement between the Baudoin Index estimate and the actual (cataloged) sex based on left occipital condyle measurements in skulls from the Center for Studies in Forensic Anthropology (FOP / UPE), 2018.

Baudoin Index – Left Occipital Condyle						
		Male *n* %	Female *n* %	Unclear *n* %	TOTAL	*P*-value
Cataloged sex	Male	32 (29.6)	57 (52.8)	19 (17.6)	108 (100.0)	
	Female	27 (26.7)	53 (52.5)	21 (20.8)	101 (100.0)	$P^{(1)} = 0.804$
	TOTAL	59 (28.2)	110 (52.6)	40 (19.1)	209 (100.0)	

(1) Pearson's Chi Square test.

4 DISCUSSION

Conventional methods may not be applicable for estimating identity when human remains or fragments are compromised due to different reasons, for instance, mass disasters, explosions, and mutilations. In these cases, the use of secondary human identification methods is required.

The skull base is protected by a large amount of soft tissue, where muscles, tendons and ligaments are inserted. Because they are in a privileged location, the occipital condyles may be one of the only elements available for estimating sex[10], which reinforces their importance to the forensic practice.

In our study, the means of the four occipital condyle measures were higher in males. Moreover, except for the width of the right occipital condyle, the other measures showed significant sex-related differences. These results partially agree with those of Galdames et al.[11] and Oliveira[12], who showed significant sex-related differences in occipital condylar measures. In addition, Galdames et al.[11] further reported that there were no significant differences between the right and left condylar widths.

Our findings showed that only the right-side BI value was found to be correlated with sex ($P < 0.05$). In addition, the correlational analysis between the sex estimates and the actual

(cataloged) sex of the specimen showed that agreement rates were lower in males than females. This is consistent with studies in other Brazilian samples[12,13], but it is in contrast with the study by Galdames et al. (2010)[11] in a sample from southeastern Brazil.

Region-specific studies are needed for the Brazilian population, which is composed of individuals from different origins, among them, African, European and indigenous[14,15]. Of note, the studies by Galdames et al.[11] and ours used samples from different regions of Brazil, which may explain the variability of the results.

The great miscegenation existing in Brazil reflects its colonization background. The sample used in our study is from the Northeast, a region where a great number of European individuals settled down, mainly Portuguese and Spanish, as well as where the first capital of Brazil was established. In addition, there was a great influence of Africans in the area, who accounted for the strongest component of the ancestry[16,17]. On the other hand, in the South and Southeast regions of Brazil, the European standard was more pronounced than the African, particularly due to Italian and German influence during the 19th and 20th centuries. Hence, even within the same country, region-specific characteristics should be considered for more accurate estimates based on the genetic influences of each ancestry[11,12,13].

Overall, the BI showed a low agreement rate for sex estimation, with a stronger correlation in females (right-side BI, 59.4%; left-side BI, 52.5%) than in males (right-side BI, 38.0%; left-side BI, 29.6%). This corroborates the studies carried out by Galdames[11], Oliveira[12] and Biancalana[13], who also reported a higher, albeit non-significant, agreement rate in females.

Although the BI has been deemed by some authors to be effective in estimating human sex, there are few studies in the literature testing its applicability to different populations[8,9]. Taken altogether, our findings indicate that the BI seems to have a poor applicability for accurately determining sex in a sample of northeastern Brazilians.

5 FINAL CONSIDERATIONS

Occipital condyle measures showed significant sex-related differences, except for the width of the right occipital condyle. However, there was a low agreement rate between the Baudoin Index estimates and the actual (cataloged) sex. Thus, the Baudoin Index is not suitable for estimating sex in the study population.

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CONFLICT OF INTEREST DECLARATION

The authors declare that have no conflict of interest that might constitute an embarrassment to the publication of this article.

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