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Determinations of Cranial Dimorphism in Sagittal Section in CT Scans

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Abstract. The objective of this study was to analyze if the linear measurements performed on 206 CT scans are dimorphic and can be used as an auxiliary method for forensic identification as a secondary method according to INTERPOL 2014. A logistic regression model was developed to determine the sex of the individual analyzed. The measurements were performed on computed tomography of the Osteological Biobank and tomography of FOP_UNICAMP, in 117 male and 89 female CT scans with known age, ancestry and cause of death. OnDemand3D® software was used for the following measures: sella turcica (center) to nasal suture, sella turcica (center) to anterior nasal spine, sella turcica to ENP, sella turcica (center) to start; Nasal suture to ENA; Nasal suture to the ENP, in the median sagittal section. The Kolmogorov-Smirnov test was used to establish the distribution and equality of variances (homoscedasticity) of the variables under study. The unpaired t-test and the Pearson correlation coefficient were conducted, resulting in a logistic regression using the Stepwise-Forward method for sex. This study was approved by CAAE

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54171916.0.0000.5418. It was verified that all measures studied are dimorphic, but the β of the measures PPST-ENA; SNRE-ENA; SNRE-ENP; ENA-ENP were the most statistically significant, being selected to determine the multiple model. The logistic regression model was created: [Logit: -19.909 + 0.177 (SNRE-ENA) + 0.231 (ENA-P)]. The model obtained in this study, presented a 77.2% accuracy, being a good result to be used as a coadjuvant method to other sex estimation methods in mixed populations, such as Brazil.
Keywords: Forensic dentistry; Sex characteristics; Forensic anthropology; Computed tomography.

1. Introduction

The Legal or Forensic Dentistry aims at the applicability of the fundamentals of dentistry in legal matters[1]. The methodology is based on records obtained ante-mortem and post-mortem, in unique patterns (there is no disagreement) capable of naming the individual analyzed, also known as positive identification[2].

However, in this last century, Forensic Odontologists, assigned to institutes of medicine and dentistry, stimulated by national scholars, cover numerous gaps and have dedicated themselves to study Forensic Physical Anthropometry, DNA analysis, as well as the implementation of a standardized identification process by international entities such as the INTERPOL[3].

INTERPOL[3] (2014) differentiated the methods of identification as either primary (allow positive identification), such as dactyloscopic exam, dental exam, DNA exam and numbered orthopedic prosthesis) or secondary (do not allow the positive identification but, accelerate the process), in this group there are studies of physical anthropometry and facial reconstruction (2D and 3D).

Through the anthropological method, sex, age, stature and ancestry can be estimated. It is noteworthy that sexual differentiation plays an important role in identifying bone remnants of missing individuals, reducing the percentual of unidentified individuals[1].

Many researchers[4-6], have already proved that bones with greater capacity of differentiation are pelvis, skull, mandible and femur.

The estimation of sex is one of the four pillars of the anthropological study, and can be performed by means of metrical analysis or visual (qualitative) analysis of the structural characteristics of the skull[7].

In the qualitative study, the male skull has larger characteristics than the female skull, in diameter, weight, bone thickness and has thicker or coarser structures, since the muscular insertions are stronger[8,9]. In the quantitative study, more metric data obtained can be used in tables or formulas used as co-adjuvants to other forensic identification methods, to make the results more reliable[10].

The CT scans are used for various applications being used in the study of many diseases and may also be used in studies of forensic sciences[11].

In the interim, the anthropometric studies consist of measurements and analysis in CT scans[12].

The anthropometric measurements from images were introduced 100 years ago, but because of the limitations, differentiations of soft tissues, densities and overlaps in three-dimensional spaces, the conventional X-ray was slowly replaced by CT scans[13-16].

In addition, CT scans offer several advantages by locating and identifying metal objects (PAF) in bodies, estimating the severity of the injury, accelerating the process and bringing benefits such as image quality, volume, area, etc[17].

The use of Computed Tomography enables the promotion of facial reconstruction through three-dimensional CT for individual identification[17].

With this possibility, the professional of Legal Dentistry can use this method in the identification, using the correct technique and accurate interpretation of the obtained information. When estimating age and sex, the ancestry of the population should be treated with care, as different population groups present variations in bone and dental characteristics[1].

In the present study, the aim was to perform linear measurements on computed tomography, to demonstrate that they are dimorphic and to obtain a viable logistic regression model for the estimation of sex as a secondary method of forensic identification.

2. Proposition

This study had the following objectives:

- verify whether the measures (Sella turcica (center) to Nasal Suture, Sella turcica (center) to ENA, Sella turcica (center) to ENP, Sella turcica (center) to Inium, Nasal suture to ENA, Nasal suture to ENP) are dimorphic;

- elaborate a model to estimate sex through linear measures in cranial CT scans.

3. Methodology

3.1. CT Scans

In the present aim 206 CT scans from the Osteological and Tomographic Biobank of FOP/UNICAMP were analyzed; of these, 117 scans belonged to male individuals and 89 to female individuals, all with known age, ancestry, and cause of death. Such scans were performed using a scanner i-CAT cone beam (Imaging Science International LLC, Hatfield, USA) with voxel of 0.4 mm³ and time of purchase of 8.9 seconds. The software OnDemand3D™ (Cybermed, Irvine, USA) was used for measurement and analysis.

Measures used (Figures 1):

Figure 1. Measures used in the study, definition and image. Obs.: In obtaining CT scan, the face of the skull was turned down. a) Anterior Nasal Spine - Posterior Nasal Spine (ENA-ENP). b) Posterior side of the Sella turcica - Anterior Nasal Spine (PPST-ENA); c)Posterior side of the Sella turcica - Inio (PPST-I); d) Posterior side of the Sella turcica - Nasal Suture External Region (PPST-SNRE); e) Nasal Suture External Region - Anterior Nasal Spine (SNRE-ENA); f) Nasal Suture External Region - Posterior Nasal Spine (SNRE-ENP); g) Posterior side of the Sella turcica - Posterior Nasal Spine (PPST-ENP).

3.2. Analysis of the quantitative data obtained

After descriptive data analysis, we found that, according to Szklo and Nieto[18] (2000), there was excellent agreement (ICC≥0.75) both in the inter-examiner analyses and in the intra-examiner analyses for the abovementioned measures. Once calibrated with standard of excellence, the remaining measures were finalized, totaling 206 scans.

Data analysis was conducted by the Kolmogorov-Smirnov test to analyze the distribution and equality of variances (homoscedasticity) of the variables under study, respectively. Unpaired t-test and Pearson correlation coefficient were also conducted. A logistic regression was obtained by the Stepwise-Forward method.

For data analysis, the program IBM@ SPSS@ 25 Statistics was used.

4. Results

Intra-operator calibration was performed using ANOVA Test, whose measurements were carried out in three moments for all the measures proposed in the study, with a month interval between each measurement. In this case, the F-critical value (rejection area) and the F value (Fisher-Snedeco) were verified, if the F value is higher than the F-critical value, the hypothesis of invalidity is rejected, being accepted the alternative hypothesis. As seen in Table 1, all values of F were lower than those of F-critical, thus, H_0 was accepted, demonstrating that there was significant variability in the measurements performed by the examiner, which confirms the repeatability and reliability of measurements.

H_o: There is no difference between the three measurements

H1: There is difference between the three measurements

Table 1. Distribution of Anova test data for intra-examiner replicability.

Measure	F/F-critical	p
PPST–SNRE	0.028129000/3.123907	0.972273*
PPST-ENP	0.014660798/3.129644	0.985449
PPST–ENA	0.006825864/3.123907	0.993198*
PPST-I	0.010701549/3.123907	0.989357*
SNRE-ENA	0.023860778/3.123907	0.976429*
SNRE–ENP	0.103753758/3.123907	0.901582*
ENA–ENP	0.145341759/3.123907	0.86498*

4.1. Descriptive statistics

Table 2 shows that the average age of the skulls of this sample obtained an average of 58.37 years with minimum value of 15.0 and maximum of 100.00 years and a standard deviation of ±18.21.

Regarding the measures of the study, the one with greater variability was PPST-I with the average of 97.99 (±8.93), and the one with smaller average value was the measure PPST-ENP with 49.24 (±6.63).

Table 2. Distribution of descriptive statistics data.

	n	Minimum	Maximum	Mean	Standard Deviation	Variance
PPST–SNRE	206	56.8	82.0	69.80	3.96	15.69
PPST–ENP	206	37.5	91.8	49.24	6.63	43.95
SNRE – ENA	206	35.4	98.7	49.597	6.5395	42.765
PPST – ENA	206	43.9	97.7	83.597	8.3146	69.132
PPST – I	206	11.4	115.6	97.299	8.9337	79.810
SNRE – ENP	206	43.2	82.1	65.587	5.5558	30.867
ENA – ENP	206	22.5	72.4	49.982	4.5923	21.089
Age	206	15.0	100.0	58.369	18.2110	331.639

Figure 2 shows that there is a statistically significant difference between male and female sexes in the measures: PTSD-SRNE, SRNE-ENA-ENP with values closest to the median.

Figure 2. Box Plot for all the measures carried out.

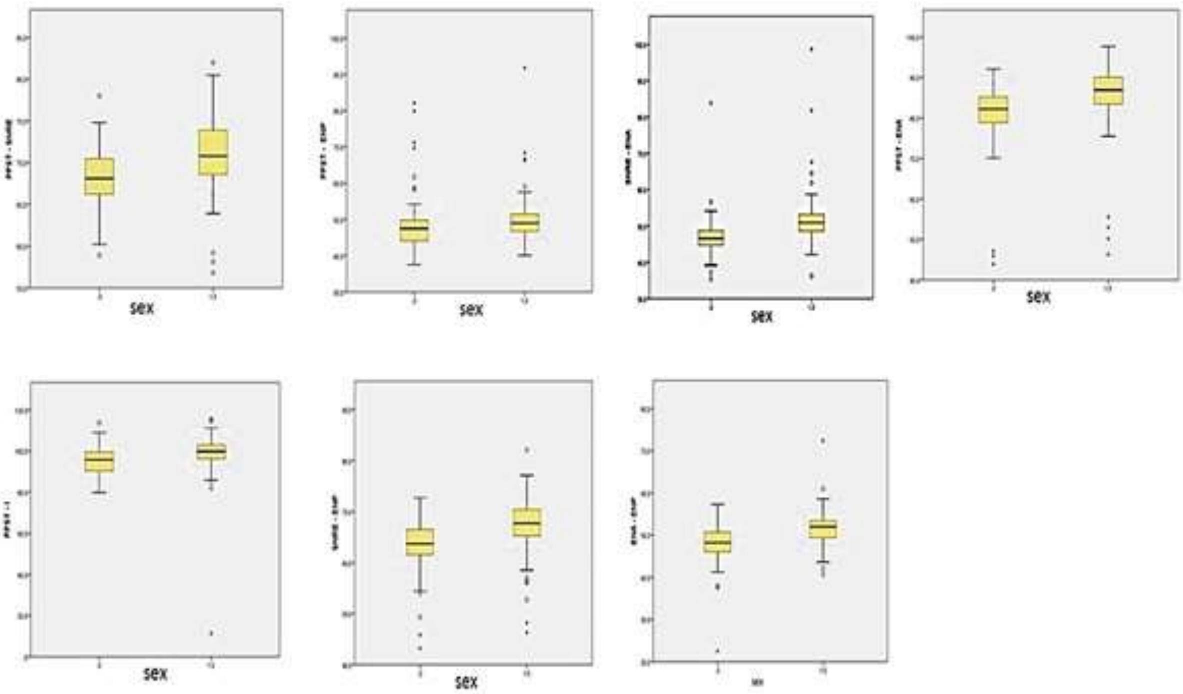

Table 3. Data distribution and Paired t-test

MEASURES	T	Df	Sig. (2 ends)	Mean difference	Standard error of difference	95% Confidence Interval of the Difference	
						lower	upper
PPST – SNRE	-5.267	204	.000	-2.7606	.5241	-3.7939	-1.7272
	-5.396	202.103	.000	-2.7606	.5116	-3.7694	-1.7518
PPST – ENP	-1.564	204	.119	-1.4538	.9293	-3.2859	.3784
	-1.521	166.600	.130	-1.4538	.9557	-3.3406	.4331
PPST – ENA	-4.435	204	.000	-4.9655	1.1196	-7.1729	-2.7580
	-4.443	190.767	.000	-4.9655	1.1177	-7.1701	-2.7609
PPST – I	-2.909	204	.004	-3.5900	1.2343	-6.0236	-1.1564
	-3.039	203.351	.003	-3.5900	1.1814	-5.9193	-1.2607
SNRE – ENA	-5.116	204	.000	-4.4412	.8680	-6.1527	-2.7298
	-5.287	203.825	.000	-4.4412	.8400	-6.0974	-2.7851
SNRE – ENP	-5.589	204	.000	-4.0768	.7295	-5.5151	-2.6385
	-5.614	192.673	.000	-4.0768	.7262	-5.5091	-2.6446
ENA – ENP	-6.444	204	.000	-3.8034	.5902	-4.9671	-2.6398
	-6.371	180.810	.000	-3.8034	.5970	-4.9814	-2.6254

4.2. Logistic regression

Assumptions

1) Y, dependent variable (Sex), is a dichotomous variable (0.1);

2) To perform a logistic regression analysis, the values of Y are assumed to be independent. This assumption was satisfied, because each individual is an independent observation;

3) Binomial error

Then the seven proposed measures were tested by the study as shown in Table 4, with the purpose of assessing the significance of the variables using the Wald test and of verifying the significance of the model by the likelihood ratio test. The results showed that the β of measures PPST – ENA, SNRE-ENA; SNRE-ENP and ENA-ENP showed statistical significance, being selected for the determination of the multiple model. The simple model was not significant, so it was not chosen for the multiple model.

Table 4. Distribution of the univariate logistic regression analysis for sex estimation.

							95%CI for EXP(B)	
	B	S.E.	Wald	df	Sig.	Exp(B)	lower	Upper
PPST	–.032	.056	.322	1	.570	1.032	.925	1.152
SNRE	.050	.032	2.400	1	.121	1.051	.987	1.120
PPST – ENP	.077	.032	5.904	1	*.015	1.080	1.015	1.149
PPST – ENA	.029	.019	2.384	1	.123	1.029	.992	1.068
PPST – I	.141	.037	14.248	1	*.000	1.152	1.070	1.239
SNRE – ENA	.093	.041	5.172	1	*.023	1.097	1.013	1.189
SNRE – ENP	.125	.053	5.570	1	*.018	1.134	1.021	1.258
ENA – ENP Constant	-32.860	5.241	39.309	1	.000	.000		

To analyze the factors associated with sex estimation, a multiple logistic regression analysis was held, in which the variables with “p” value of the univariate model ≤20 were selected. The order of entry in the multiple model was in accordance with the increasing values of “p”.

The variables that obtained p values lower than ≤20 were tested, one by one, in ascending order of p. Therefore, in the decision for the best model, the variables SNRE-ENA and ENA-ENP were established, as shown in Table 5.

Table 5. Multiple logistic regression for sex estimation.

	B	S.E.	Wald	Df	Sig.	Exp(B)	95%CI for EXP(B)	
							lower	Upper
SNRE – ENA	.177	.045	15.222	1	.000	1.194	1.092	1.305
ENA – ENP	.231	.051	20.747	1	.000	1.260	1.141	1.391
Constant	-19.909	3.215	38.346	1	.000	.000		

Based on the results obtained in Table 5, it was possible to made the logit model for sex estimation

*Model [Logit = -19.909 + 0.177*SNRE-ENA+ 0.231*ENA-ENP].*

Table 6 shows that the method results in 82.1% sensitivity, 70.8% specificity and 77.2% accuracy, showing more effectiveness in sex estimation than the mere random accuracy.

Table 6. Correct percentages of sex estimation.

		Model prediction		
		Sex		
		F	M	% correct
Sex	F	63	26	70.8
	M	21	96	82.1
General percentage				77,2

[a] Cutoff value is 0.500

5. Discussion

In disasters of epic proportions and even encounters of skeleton spawning sites, the search for the establishment of identity begins with the study of forensic physical anthropometry.

In Brazil, the anthropometric study is started with the estimation of sex, followed by the study of age and height and ancestry. Once defined, one can direct the collection of ante-mortem and post-mortem data to enable the process of identification by the teeth or DNA (Daruge[1] et al., 2017).

The prior knowledge of the sex, age, ancestry and stature of the skeleton under analysis allows a gain in agility and quality of the skeletal identification conditions (Francesquini Jr.[7], et al., 2007).

To generate more safety in the anthropometric study, there is a need to validate in the Brazilian population all the models to estimate the sex. This validation can be done on skeletons or be performed on CT scans.

The creation of the Osteological and Tomographic Biobank where they have data (sex, age, ancestry, cause of death, among others) facilitates the realization of Brazilian anthropological models, besides allowing calibration, validation and greater security in human identification.

However, it is important to highlight the difficulty of obtaining intact skeletons, the cost generated, the difficulty of organization and cataloging, and especially the maintenance and use by numerous researchers.

In Brazil, Cunha[19] et al. (2018) evaluated all Brazilian collections, validating them and presenting them to the scientific community. The geographic distribution of the collections, although they do not represent all the states, will allow that over the years there will be regional tables for sex, ancestry, age, stature, among others.

The use in the present study of Computed Tomography, initially performed by the ease of use of the sample may be fractured, and a tomography of the same in a post mortem situation may facilitate the determination of sex.

The logit generated when applied in the same sample generated a degree of success of 77.2%, which coincides with Zheng[20] et al. (2018) that studying tomography of jaws obtained 87.4% of correct with the obtained model.

Already Venkatesh[21] et al. (2010) studying lateral and anterior posteral teleradiographs of southern Indians and Tibetans found degrees of accuracy of 81.5% and 88.2%. The same happens with Zaafrane[22] et al. (2017), who studied computer tomography obtained from tunisians obtaining a model with a degree of success of 85.9%. Ekizoglu[23] et al. (2016) studied computerized tomography of Turks and verified that the bizigomatic diameter was the most dimorphic structure studied and the model generated obtained a degree of correctness of 87.5% for women and 87% for men. Isaza[24] et al. (2014) studied 16 measurements in the endocranium in 249 individuals of Medelin Colombia and obtained 89.7% accuracy.

Franklin[25] et al. (2013) studied 18 measurements on 400 computerized tomographies of Western Australians and found that the bizigomatic width and maximum length of the skull and base are the most dimorphic.

As seen so far the bizigomatic width is one of the most dimorphic linear measurements, thus remaining in almost all the ancestry already studied in the world.

It is also worth noting that the studies also compare skeletons from different historical periods as performed by Bejdová[26] et al. (2017) and these allow the use of the model obtained in archaeological studies (Gao[27] et al., 2018).

There is a need for continuity in the anthropometric studies in Brazilians, aiming to contemplate all the different ancestral / sex differences existing in each region of the country.

5. Conclusions

The mathematical model obtained can be reproduced for the estimation of sex, since it presented an accuracy of 77.2%. However, it should be used as an auxiliary method in conjunction with another method of forensic identification.

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