J Forensic Sci, July 2008, Vol. 53, No. 4
doi: 10.1111/j.1556-4029.2008.00759.x
Available online at: www.blackwell-synergy.com

TECHNICAL NOTE

Sophie A. Veyre-Goulet,[1] *M.Sc.; Catherine Mercier,*[2,3,4] *Ph.D.; Olivier Robin,*[1] *Ph.D.; and Claude Guérin,*[3,5] *Ph.D.*

Recent Human Sexual Dimorphism Study Using Cephalometric Plots on Lateral Teleradiography and Discriminant Function Analysis

---

ABSTRACT: The examination of skull sexual dimorphism has been the subject of numerous morphologic and craniometric studies, but the disadvantage of these studies is that they are dependent on the experience of the operator and involve subjectivity. In 1996, a team from Taiwan refined the methods enabling the sex of an individual to be determined using cephalometric plots made from lateral teleradiography. To validate their work using a European population, 114 dry skulls (59 men and 55 women) were examined. Cephalometric plots were made on lateral teleradiography with an orthodontic software and 18 cephalometric variables were analyzed. Sex was determined with 95.6% accuracy using the 18 variables discriminant function. A subset of eight variables was selected and could predict sex with the same accuracy. In conclusion, it can be said that skull-sexing methods using lateral teleradiography seem always suitable but the most indicative variables could differ relative to the ethnic population concerned.

KEYWORDS: forensic science, physical anthropology, sex determination, skull, lateral roentgenographic cephalometrics, discriminant function analysis

When human bones are discovered, the first question asked is "Are they male or female?" This is of interest in two fields: anthropology and forensic science. Among the bones of the human skeleton, the pelvis is the most determinant (1), but, because of its complex shape, it is delicate and often found in a very poor condition. The skull, on the other hand, is usually better preserved and more readily exploitable (2).

For this reason, many authors have concentrated on the skull for determining the sex of an individual. Several methods have been refined. Initially, morphologic examinations were developed. These were qualitative methods making use of descriptive criteria (3–5). The disadvantage of such methods is that they lack objectivity and are dependent on the experience of the operator (6).

Craniometric examination was also developed, and this is a quantitative examination involving taking direct measurements of the skull (7,8).

In 1958, Céballos and Rentschler (9) were the first to work on teleradiography for determining sex from the skull. Other authors succeeded them (10–15) using both posteroanterior and lateral teleradiography.

In 1996, Hsiao et al. (16) conducted lateral teleradiography on a sample of 50 males and 50 females from Taiwan. Using 18 variables from cephalometric plots obtained from the teleradiography plates, they claimed to be able to determine the sex of an individual with 100% accuracy. Furthermore, of the 18 variables, three are more indicative than the others are, and the authors say that they can determine the sex of a subject to 98% accuracy by using these three variables alone.

At the end of their study, the Taiwanese authors suggest their method should be tested on a different ethnic population. The purpose of our research therefore was to validate the Taiwanese method on a European population.

Materials and Methods

The sample we studied comprised 114 dry skulls (59 men and 55 women) from the "Museum d'Histoire Naturelle" in Lyon. This collection dates from the end of the 19th century and comes from deceased people in hospital and the dead body where not claimed by the family. For each body, sex and age were listed in an index. All the subjects came from the Rhône-Alpes region in France. The subjects selected were aged between 20 and 55 at the time of their death, in other words, after puberty and before signs of senility appeared (4).

Lateral teleradiography was conducted on each skull. The plates were made using radiography equipment that established a focal-plate distance of 4 m. They were digitized with Epson Expression 1640XL Scanner (Epson America, Inc., Long Beach, CA). Then, the cephalometric traces were made by an orthodontic software. Nineteen cephalometric points were identified (Table 1) which enabled the identification of 18 cephalometric variables as described in Hsiao et al. (16) (Table 2). There were eight angles (°), nine linear measurements (mm), and a proportional measurement (%). The same operator conducted all the cephalometric plots.

---

[1] UFR d'Odontologie, Université Claude Bernard Lyon 1, France.

[2] Hospices Civils de Lyon, Service de Biostatistiques, Lyon, F-69424, France.

[3] Université de Lyon, Université Lyon 1, Villeurbanne, F-69622, France.

[4] CNRS, UMR 5558, Laboratoire Biostatistique Santé, Pierre-Bénite, F-69495, France.

[5] UMR 5125 «paléoenvironnement et paléobiosphère», CNRS, Lyon, France.

Received 28 July 2007; and in revised form 18 Oct. 2007; accepted 18 Nov. 2007.

TABLE 1—*Cephalometric landmarks.*

Landmark	Description
B (Bregma)	Point at which sagittal and coronal sutures meet
M (Metopion)	Point where the line that connects the highest points of the frontal eminences crosses the sagittal plane
G (Glabella)	Most anterior point in the midsagittal plane between the superciliary arches
Sg (Supraglabellare)	Most posterior midline point in the supraglabellar fossa, the concavity between glabella and metopion
N (Nasion)	Most anterior point on the frontonasal suture in the midsagittal plane
V1	Upper parameter of the frontal sinus cavity
V2	Lower parameter of the frontal sinus cavity
H1	Anterior parameter of the frontal sinus cavity on bregma to nasion line, the line from the inner location of bregma to nasion
H2	Posterior parameter of the frontal sinus cavity on bregma to nasion line
S (Sella)	Midpoint of sella turcica, hypophyseal fossa
Or (Orbitale)	Lowest point on the lower margin of the bony orbit
Po (Porion)	Top of the external auditory meatus
Op (Opisthocranion)	Most prominent point of the occipital bone in the midline
I (Inion)	Most prominent point of the external occipital protuberance
O (Opisthion)	Midpoint of the posterior border of the foramen magnum
Ba (Basion)	Most inferior posterior point in the sagittal plane on the anterior rim of the foramen magnum
Ma (Mastoidale)	Lowest point of the mastoid process
B1	Anterior parameter of the mastoidal width at the level of cranial base
B2	Posterior parameter of the mastoidal width at the level of cranial base

Reprinted, with permission from Hsiao et al. (16), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

TABLE 2—*Cephalometric variables.*

Variables	Description
Angular, °:	
1. GMSN	Angle between the glabella to metopion line and the sella to nasion line (SN)
2. GMFH	Angle between the glabella to metopion line and the porion to orbitale line (Frankfort horizontal plane, FH)
3. GMBaN	Angle between the glabella to metopion line and the basion to nasion line (BaN)
4. GSgM	Angle between the metopion to supraglabellare line and the supraglabellare to glabella line
5. IOpSN	Angle between the inion to opisthocranion line and the SN line
6. IOpFH	Angle between the inion to opisthocranion line and the FH line
7. IOpBaN	Angle between the inion to opisthocranion line and the BaN line
8. OIOp	Angle between the opisthocranion to inion line and the inion to opisthion line
Linear, mm:	
9. SgGM	Distance between supraglabellare and the glabella to metopion line
10. GSgN	Distance between glabella and the supraglabellare to nasion line
11. FSHt	Frontal sinus height, vertical parameters of the frontal sinus cavity
12. FSWd	Frontal sinus width on bregma to nasion line
13. IOpO	Distance between inion and the opisthocranion to opisthion line
14. MaSN	Distance between mastoidale and the SN line
15. MaFH	Distance between mastoidale and the FH line
16. MaHt	Mastoid height from cranial base
17. MaWd	Mastoid width at the level of cranial base
Proportional, %:	
18. GPI	Glabella projection index = (distance between glabella and the supraglabellare to nasion line) × 100/(distance between supraglabellare and nasion)

Reprinted, with permission from Hsiao et al. (16), copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

The operator did not know the sex of the skull at the time of making the plot.

The data obtained were analyzed using SAS 9.0® (17). We used exactly the same method as used for the Taiwan data (16) and the Indian data (18), i.e., univariate student *t*-test (Satterthwaite method when variances where unequal) were performed and univariate *F*-ratios (square of *t*-test) were reported. Linear discriminant function (using pooled covariance matrix) and quadratic discriminant functions (using within group covariance matrix) were computed. Resubstitution classification and cross-validation classification (leave-one-out method) were then performed. The percentage error of classification was calculated on the full data set (resubstitution) and after cross-validation (leave-one-out). The stepwise discriminant analysis was used for the variable selection (stepwise method).

Results

The values of the 18 cephalometric variables are presented in Table 3. The mean differences for all measurements were statistically significant ($p < 0.0001$). Mean male values for angular measurements were smaller than female values, except for the angle GMSN, angle GMFH, and angle GMBaN. Mean male values for all linear measurements and the proportional variable (GPI) were larger than female values.

The stepwise discriminant analysis selected eight variables (Table 4): the distances GSgN, MaHt, SgGM, FSHt, MaWd, and FSWd, the angle GMSN, and the GPI. The *F*-value for a variable indicates its statistical significance in sex discrimination, i.e., it is a measure of the extent to which the variable makes a unique contribution to the prediction of sex. Wilks lambda is used to test the null hypothesis that the populations have identical means on *D*. Wilks lambda is $= \frac{SS_{\text{within\_groups}}}{SS_{\text{total}}}$, so the smaller the Wilks lambda the more doubt cast upon that null hypothesis. For our data, $p < 0.0001$. We can determine how much of the variance in the grouping variable is explained by our predictor variables by subtracting the Wilks lambda from one, we obtain the squared canonical correlation. For our data, 80% of the variance was explained with the eight variables.

The discriminant analysis was performed on the 18 variables and on the eight selected variables (Table 5). The Linear discriminant analysis (LDA) function gave a better prediction than the quadratic discriminant analysis (QDA) function with 4.4% of classification error for both 18 and eight variables versus 11.4% and 8.8%, respectively. The reliability (100—CV error) is at least as good for the subset of eight variables as for the total set (95.6% for both with the LDA function). To predict sex membership from a set of p predictor variables with the LDA method, a linear discriminant equation,

$$D_i = a + b_1X_1 + b_2X_2 + \ldots + b_pX_p$$

is constructed such that the two groups differ as much as possible on *D*. That is, the weights are chosen so that a discriminant score (D_i) and an ANOVA on *D* were computed for each subject; the ratio of the between groups sum of squares to the within groups sum of squares is as large as possible. For our data, the generalized squared distance (D^2) between the two sexes was 16.04 with the eight variables predictor and 19.16

TABLE 3—*Means, standard deviation, and univariate F-ratios for 18 cephalometric variables of 114 European adult samples (59 male and 55 female).*

	Male (n = 59)		Female (n = 55)		
Variables	Means	SD	Means	SD	F-Ratio
OIOp	139.213	8.181	146.318	7.1638	24.1875
IOpSN	102.262	9.78987	110	9.01938	19.1811
IOpFH	113.052	9.5876	120.721	8.84207	19.6254
IOpBaN	82.867	8.7258	92.0340	8.91239	30.7744
GSgM*	164.392	7.86962	174.345	2.86639	78.2547
GMSN	83.018	5.81218	88.805	5.50877	29.6680
GMFH	72.228	6.21989	78.084	5.31097	29.0186
GMBaN	101.905	5.67736	106.771	4.81339	24.1886
SgGM*	1.636	0.754775	0.50546	0.324160	105.2504
MaWd	19.526	2.71668	13.9362	2.42933	133.3781
MaSN	42.358	5.04388	37.0598	4.46153	35.0814
MaHt	11.723	2.12516	8.0250	1.73289	102.8116
MaFH	29.358	3.02258	24.8817	2.65413	70.1691
IOpO	10.724	3.26464	7.63	2.74681	29.7637
GSgN*	3.833	1.08017	1.84776	0.52425	152.2059
FSWd	13.181	2.47245	9.5525	2.03068	72.7109
FSHt	31.053	3.946	22.9895	3.82077	122.5421
GPI*	19.876	5.783	13.5927	4.2030	43.4957

*Unequal variances between sexes.

with the 18 variables predictor. The linear discriminant function (weights b_i and constant a) for male and female with eight variables is given in Table 4.

Discussion

The examination of skull sexual dimorphism has been the subject of numerous morphological and craniometric studies, but the disadvantage of these studies is that they are greatly dependent on the experience of the operator and involve subjectivity. However, the teleradiographic examinations developed more recently are of interest because they are more objective, standardized, and reproducible. Moreover, according to many authors, the most indicative regions of the skull in terms of sexual identification are the frontal regions and the base of the skull.

Therefore, following the example of the Taiwanese team, these two regions were examined to identify the following anatomical features: the glabella, the frontal sinus, the external occipital protuberance, and the mastoid processes. As Hsiao et al. (16), the two reference plans used in this study were the Frankfort plan (S-Na) and Basion-Nasion plan, which are the most frequently used in cephalometric analysis of profile teleradiography.

TABLE 5—*Classification results of sex determination from cephalogram with a linear discriminant function (LDA) or a quadratic discriminant function (QDA), for either the 18 variables, or the eight selected variables.*

Model	Data	Resubstitution Error %	CV Error %
18 variables LDA	Total	2.6	4.4
	Male	5.1	5.1
	Female	0.0	3.6
8 variables LDA	Total	4.4	4.4
	Male	5.1	5.1
	Female	3.6	3.6
18 variables QDA	Total	5.3	11.4
	Male	10.2	18.6
	Female	0.0	3.6
8 variables QDA	Total	4.4	8.8
	Male	5.1	6.8
	Female	3.6	10.9

Of the nine linear measurements considered, all values are greater in males than in females. This confirms the conclusions of many authors including Patil and Mody (17) who found linear dimensions to be greater in men than in women.

The 18 cephalometric variables examined on our European population were confirmed to be a reliable predictor for sex. A subset of eight variables was selected and could predict sex with the same accuracy: Distances GSgN, MaHt, SgGM, FSHt, MaWd, and FSWd, angle GMSN, and GPI.

The GSgN, SgGM, GMSN, and GPI variables only concern the glabella area. The FSWd and FSHt variables, in fact, translate the width and height of the frontal sinus. MaWd and MaHt translate the width and height of the mastoid processes.

Also, between the two anatomical regions examined, the frontal region would appear to be the most determinant. Among the eight most significantly different variables, between male and female, six are found in that region.

The linear discriminant function enables sex determination with an accuracy of 95.6% in a random sample of 114 European crania. This accuracy was the same for both 18 and the eight selected variables, and was better than the ones obtained with quadratic discriminant functions (88.6% with 18 variables and 91.0, 2% with eight variables).

We noticed that the eight selected variables were not exactly the eight more correlated with the discriminant function (GSgM and MaFH would replace GMSN and GPI for this criteria). However, the discriminant function is unstable unless there are 20 times more cases than there are variables, which is not the case on our data. The cross validation is especially important to limit the optimism of the model to predict sex with data already used to compute the predictor. The cross validation method

TABLE 4—*Variables selected with the stepwise discriminant analysis. Stepwise selection summary and coefficients in the eight variables linear discriminant function for males and females.*

Variables	F-Value	Pr > F	Wilk's Lambda*	Average Squared Canonical Correlation	Male Coefficients (Constant = −298.44)	Female Coefficients (Constant = −269.68)
GSgN	152.21	<0.0001	0.424	0.576	−93.13	−88.39
MaHt	42.65	<0.0001	0.306	0.694	0.58	−0.29
SgGM	17.03	<0.0001	0.265	0.735	6.51	4.32
FSHt	10.52	0.0016	0.242	0.758	0.99	0.74
GMSN	5.94	0.0164	0.229	0.771	2.94	3.28
MaWd	5.70	0.0187	0.218	0.782	16.92	15.16
GPI	7.19	0.0085	0.204	0.796	1559	1430
FSWd	3.62	0.0598	0.197	0.803	−1.48	−1.98

*Pr < lambda always significant under the 0.0001 level. D^2 = 16.037.

(leave-one-out) used to reproduce the Taiwanese and Indian analyses may not be optimal to reduce the overestimate of the predictive value. Using this predictor on new data could lead to a lower predictive value for this reason and also because of the secular effect and because of today's variability in the European population.

Conclusion

It is possible to apply the method developed by the Taiwanese team for determining the sex of a European skull with their 18 cephalometric variables.

It is a simple and reliable method that can be readily applied in forensic science, in anthropology, and in human palaeontology. A subset of eight variables could be sufficient to determine the sex with a similar accuracy but should be validated on new independent data.

Acknowledgments

The authors would like to thank the staff of Centre de Conservation et d'Étude des Collections—Muséum d'Histoire Naturelle in Lyon and M. Ramel for their help; W. Sadouni for his support with the orthodontic software; and J.P. Aknin for his counseling.

References

1. Novotny V. Sex determination of the pelvic bone: a systems approach. Anthropology 1986;24:197–206.
2. Rougé D, Telmon N, Arrue P, Larrouy G, Arbus L. Radiographic identification of human remains through deformities and anomalies of post-cranial bones: a report of two cases. J Forensic Sci 1993; 38(4): 997–1007.
3. Ferembach D, Schwidetzky I, Stloukal M. Recommandations pour déterminer l'âge et le sexe sur le squelette. Bull Mem Soc Anthropol Paris 1979;13(6):7–45.
4. Krogman WM, Iscan MY. The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas, 1986.
5. Clement JG, Ranson DL. Craniofacial identification in forensic medicine. New York: Oxford University Press, 1988.
6. Novotny V, Iscan MY, Loth SR. Morphologic and osteometric assessment of age, sex and race from the skull. In: Iscan MY, Helmer RP, editors. Forensic analysis of the skull. New York, NY: Wiley-Liss, Inc., 1993;71–81.
7. Giles E, Elliot O. Sex determination by discriminant function analysis of crania. Am J Phys Anthropol 1963;21(1):53–68.
8. Demoulin F. Importance de certaines mesures crâniennes (en particulier de la longueur sagittale de la mastoïde) dans la détermination sexuelle des crânes. Bull Mem Soc Anthropol Paris 1972;12(9):259–64.
9. Céballos JL, Rentshler EH. Roentgen diagnosis of sex based on adult skull characteristics; comparison study of cephalometry of male and female skull films (frontal pro-projection). Radiology 1958;70(1):55–61.
10. Ingerslev CH, Solow B. Sex differences in craniofacial morphology. Acta Odontol Scand 1975;33(2):85–94.
11. Bibby RE. A cephalometric study of sexual dimorphism. Am J Orthod 1979;76:256–9.
12. Funayama M, Aoki Y, Kudo T, Sagisaka K. Sex determination of the human skull based upon line drawing from roentgen cephalograms. Tohoku J Exp Med 1986;149(4):407–16.
13. Inoue M. Fourier analysis of the forehead shape of skull and sex determination by use of computer. Forensic Sci Int 1990;47(2):101–12.
14. Chang HP, Kinoshita Z, Kawamoto T. A study of the growth changes in facial configuration. Eur J Orthod 1993;15(6):493–501.
15. Ursi WJ, Trotman CA, McNamara JA, Behrents RG. Sexual dimorphism in normal craniofacial growth. Angle Orthod 1993;63(1):47–56.
16. Hsiao TH, Chang HP, Liu KM. Sex determination by discriminant function analysis of lateral radiographic cephalometry. J Forensic Sci 1996;41:792–5.
17. SAS Institute Inc. SAS/SAT user's guide, Version 6, 4th ed., Vols 1 and 2. Cary: SAS Institute Inc., 1990.
18. Patil KR, Mody RN. Determination of sex by discriminant function analysis and stature by regression analysis: a lateral cephalometric study. Forensic Sci Int 2005;147:175–80.

Additional information and reprint requests:
Sophie Veyre-Goulet, M.Sc.
UFR d'Odontologie
11, rue Guillaume Paradin
69008 Lyon
France
E-mail: sophieveyre@hotmail.com