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Sex Determination by Discriminant Function Analysis of Lateral Radiographic Cephalometry*

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ABSTRACT: The present work is an attempt to develop a new method to determine sex from the skull with lateral radiographic cephalometry and discriminant function analysis. The superciliary ridges, frontal sinuses, external occipital protuberance, and mastoid processes were adopted as objects of lateral radiographic cephalometric measurements. With discriminant functions created from 18 established cephalometric variables, a total of 100 cases were classified into two sexual groups with 100% accuracy in a random sample of Taiwanese adults. Therefore, we may obtain a much greater reliability of sex determination from skulls according to this newly developed technique.

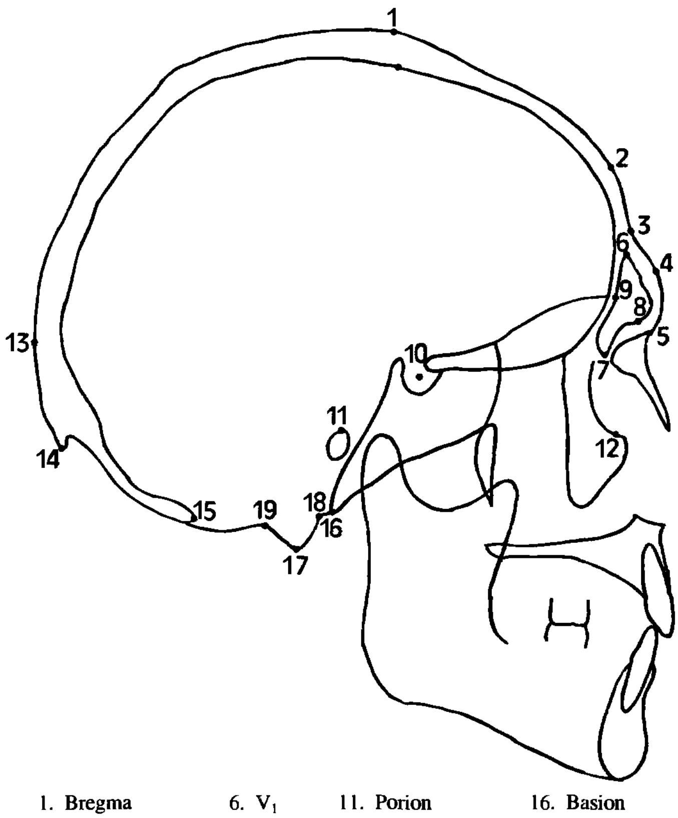
KEYWORDS: forensic science, physical anthropology, sex determination, skull, lateral roentgenographic cephalometrics, discriminant function analysis

Physical anthropologists and anatomists developed the branch of anthropometry known as craniometry or cephalometry. Because radiographic cephalometry was introduced into orthodontics by Broadbent (1) in United States and Hofrath (2) in Germany, this new technique arose in clinical and research orthodontics, as well as in the entire field of research of craniofacial growth (3). The craniofacial research advanced from craniometry (measuring the dry skull) or cephalometry (measuring the living skull, head) to radiographic cephalometry (measuring the tracing of an X-ray film of the head). The recent introduction of computer-aided analysis of cephalometric data extends the utility of the method.

In forensic anthropology, forensic dentistry, forensic medicine, and physical anthropology, the skull plays an important role in the determination of sex. Apart from the pelvis, the skull is the most readily sexed portion of the skeleton. Ability in cranial sex determination claimed by investigators shows considerable variation. Its accuracy was about 77 to 92% (4,5). A few reviews indicate what reliability may be expected from traditional visual methods or combinations of observations and measurements.

In general, male skulls are identifiable by being more robust. The female skull is characterized by weaker development of its superstructures. All bony ridges, crests, and processes are smaller and smoother in the female skull than in the male skull, especially true for the temporal line, mastoid processes, nuchal lines, external occipital protuberance, and superciliary arches or ridges. The lack or weaker development of frontal and occipital superstructures also causes a fairly characteristic difference in the profile of female and male crania (6,7).

The methods of sex determination on the skull are obviously imperfect and efforts are constantly being expended to improve them. Discriminant function analysis is increasingly utilized for



1. Bregma	6. V_1	11. Porion	16. Basion
2. Metopion	7. V_2	12. Orbitale	17. Mastoidale
3. Supraglabellare	8. H_1	13. Opisthocranion	18. B_1
4. Glabella	9. H_2	14. Inion	19. B_2
5. Nasion	10. Sella	15. Opisthion	

FIG. 1—*Cephalometric landmarks (for definitions, see Table 1).*

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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.
V_1	Upper parameter of the frontal sinus cavity.
V_2	Lower parameter of the frontal sinus cavity.
H_1	Anterior parameter of the frontal sinus cavity on bregma to nasion line, the line from the inner location of bregma to nasion.
H_2	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.
B_1	Anterior parameter of the mastoidal width at the level of cranial base.
B_2	Posterior parameter of the mastoidal width at the level of cranial base.

sex diagnosis of skeletal measurements. The present work is an attempt to develop a technique to determine sex from the skull with radiographic cephalometry and discriminant function analysis. Essentially traits of robustness enable differentiation between male and female skulls. The increase in accuracy of cranial sex determination would be expected from this new technique.

Materials and Methods

Lateral cephalometric radiographs of 100 adults were used as materials to develop our methods. These radiographs were of high quality. They were generally characterized by optimal contrast and no blurring of the anatomical structures. The sample comprised of 50 Taiwanese men and 50 women, chosen randomly from the files of the Department of Orthodontics, School of Dentistry, Kaohsiung Medical College.

Each film was traced and cephalometric landmarks were determined by one examiner who did not know the sex of the subject and checked by another examiner (Fig. 1). They were then digitized into an *x-y* coordinate system twice on two separate occasions, and the average generated values were taken as the actual measurements. The enlargement factor (11/10) of the tracing of each head film was corrected by the computer to 10% (8).

The cephalometric landmarks are given in Table 1. The cephalometric variables are given in Table 2.

The cephalometric data were treated using the SAS procedures for discriminant analysis: resubstitution classification, cross-validation classification, and stepwise discriminant analysis—stepwise selection method (9). The same data set was used both to define and to evaluate the discriminant function. This classification method is called resubstitution. The resulting estimates can be strongly optimistically biased. One way to reduce classification bias is by the cross-validation, sometimes called the leaving-one-out method. Frequently, it is inaccurately referred to as a jackknife procedure. Originally proposed by Lachenbruch (10), it involves leaving out each of the cases in turn, calculating the function based on the remaining $n - 1$ cases, and then classifying the left-out case. Because the case that is being classified is not included in the calculation of the function, the observed classification rate is a less-biased estimate of the true one.

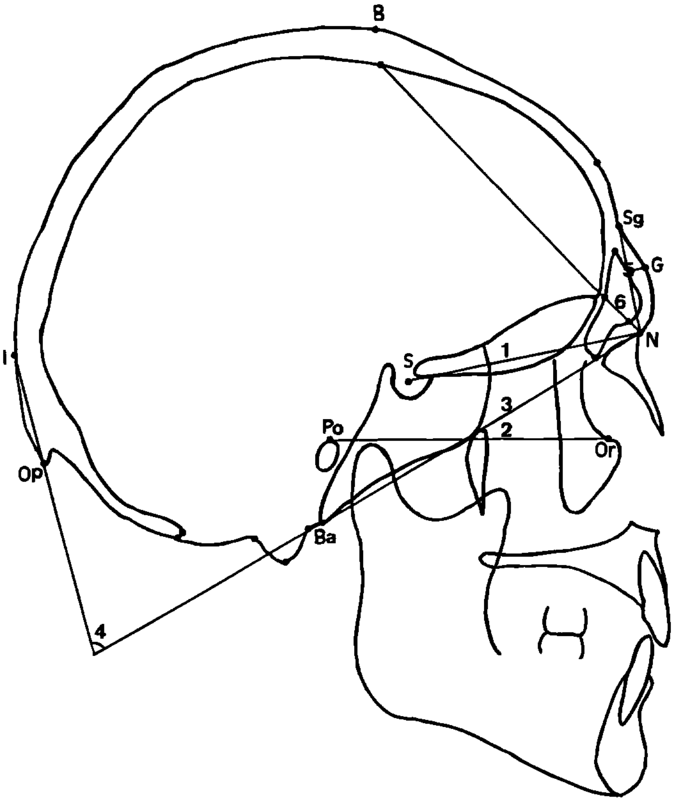
TABLE 2—*Cephalometric variables (see Fig. 2).*

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

Results

The descriptive statistics of 18 cephalometric variables of the sample of 100 Taiwanese adults is presented in Table 3. The mean differences for all measurements were statistically significant. Mean male values for all angular measurements were smaller than female values, but mean male values for all linear measurements and proportional measurement were larger than female values.

Univariate *F* tests of the mean differences between the sexes indicate that the sexes should be discriminable with respect to all measurements. Because there are two groups, the *F* value is just



1. SN (sella to nasion line)
2. FH (Frankfort horizontal plane, porion to orbitale line)
3. BaN (basion to nasion line)
4. IOpBaN (inion-opisthocranion to BaN) (°)
5. GPI (glabella projection index = GSgN × 100/SgN) (%)
6. FSWd (frontal sinus width) (mm)

FIG. 2—*Three reference lines and three critical cephalometric variables (see Table 2).*

TABLE 3—*Means, standard deviations, Wilks' lambda, and univariate F-ratios for 18 cephalometric variables of 100 Taiwanese adult samples.**

	Male (n = 50)		Female (n = 50)			
Variables	Mean	S.D.	Mean	S.D.	Lambda	F
Angular measurements, °:						
GMSN	81.04	5.62	90.40	5.40	0.576	72.17†
GMFH	74.11	5.05	83.21	5.38	0.563	76.13†
GMBaN	102.22	5.16	111.15	4.83	0.551	79.79†
GSgM	171.53	5.41	175.81	2.80	0.799	24.62†
IOpSN	90.52	6.27	94.21	5.36	0.907	9.99‡
IOpFH	97.43	5.90	101.38	4.71	0.877	13.69†
IOpBaN	56.03	7.95	73.42	5.13	0.367	169.10†
OIOp	125.25	8.29	132.40	5.05	0.783	27.17†
Linear measurements, mm:						
SgGM	1.03	0.61	0.38	0.24	0.667	48.84†
GSgN	4.46	1.32	2.10	0.66	0.433	128.38†
FSHt	32.30	6.54	24.84	5.89	0.731	35.99†
FSWd	10.70	2.79	7.40	2.34	0.705	41.06†
IOpO	20.15	6.14	16.06	3.73	0.858	16.19†
MaSN	45.23	6.47	40.82	4.59	0.864	15.44†
MaFH	30.41	4.10	27.29	3.36	0.849	17.42†
MaHt	10.27	2.74	7.28	1.79	0.701	41.90†
MaWd	19.56	3.05	16.91	2.50	0.812	22.68†
Proportional measurement, %:						
GPI	15.70	4.00	7.97	2.15	0.403	145.14†

*Degrees of freedom = 1 and 98.
†Significant under the 0.001 level.
‡Significant under the 0.01 level.

TABLE 4—*Classification results of sex determination from cephalogram of 100 Taiwanese adult samples with discriminant analysis.*

Variable	Resubstitution	Cross-validation			
GMSN	X	X			
GMFH	X	X			
GMBaN	X	X			
GSgM	X	X			
IOpSN	X	X			
IOpFH	X	X			
IOpBaN	X	X	X	X	X
OIOp	X	X			
SgGM	X	X			
GSgN	X	X			
FSHt	X	X			
FSWd	X	X			X
IOpO	X	X			
MaSN	X	X			
MaFH	X	X			
MaHt	X	X			
MaWd	X	X			
GPI	X	X		X	X
Accuracy, %	100	100	94	97	98
Male, %	100	100	94	94	98
Female, %	100	100	94	100	98

the square of the t value from the two-sample t test. Another statistic displayed in the Table is Wilks' lambda, sometimes called the U statistic.

Because of unequal group covariance matrices (x^2 = 1070.23, p = 0.0001), the discriminant function was based on the individual within-group covariance matrices (yielding a quadratic function) and not on the pooled covariance matrix (yielding a linear function) (11).

Table 4 shows the percentage of individuals sexed correctly according to discriminant functions. The IOpBaN angle has the largest F value (169.10, see Table 3). The model with IOpBaN alone classifies 94% of the sexes correctly. The model with two variables (IOpBaN and GPI) and three variables (IOpBaN, FSWd, and GPI) classifies the sexes with 97 and 98% accuracy, respectively, whereas the model with 18 cephalometric variables classifies the both sexes with 100% accuracy.

Discussion

Numerous morphological and morphometric studies have been published on sex determination from crania. In general, superciliary ridges are more prominent and frontal sinuses larger in male skulls; the external occipital protuberance and mastoid processes are also more developed. Almost all of these are structures according to which sex can be determined visually with much confidence. However, evaluation of morphological traits is considered more subjective and depends on experience of the investigator. Methods based on measurements and statistical techniques do not necessarily require this kind of subjective experience and are therefore more serviceable for use in sex determination of the skull.

Although morphometric traits seem more objective, a random set of measurements may not invariably be conclusive. The most widely used statistical technique has been multivariate discriminant analysis of sex determination for skeletal measurements. Discriminant analysis is used to classify individuals into two or more alternative groups on the basis of a set of measurements. These techniques can also be used to identify which variables contribute to making the classification (9,12). Hence, discriminant function analysis may served as an entirely objective statistical technique for sex determination.

In this work, superciliary ridges (*glabella*), frontal sinuses, external occipital protuberance (*inion*), and mastoid process (*mastoidale*) were adopted as objects of lateral radiographic cephalometric measurements. We chose the *sella* to *nasion* line, the Frankfort horizontal plane and the *basion* to *nasion* line as reference lines or planes, commonly used in lateral radiographic cephalometric analyses (13–15). Twenty-one cephalometric measurements were made on the samples, but only eighteen of these were used in discriminant function analysis. Including additional variables fails to improve substantially sex determination.

The models selected by the stepwise discriminant analysis are not necessarily the best possible models, because the selection process does not take into account the relationships between variables that have not yet been selected. Careful cross-validation can be a valuable aid in selecting a discrimination model (9).

According to discriminant functions created from 18 established cephalometric variables, a total of 100 cases were classified into two sexual groups with 100% correct results in the sample. Among 18 variables, the IOpBaN alone showed the greatest efficiency as a single discriminator, with 94% accuracy. It was possible to determine the sex of the sample with 97 and 98% accuracy with two variables (IOpBaN and GPI) and three variables (IOpBaN, FSWd, and GPI) respectively. Among these, the variable IOpBaN is an angular measurement of inion-opisthocranion to BaN, the FSWd is a linear measurement of the frontal sinus width on inner bregma to nasion line, and the GPI is a ratio measurement of the distance glabella to supraglabellare-nasion and the distance supraglabellare to nasion.

The angular and ratio measurements have been used by us and others to depict "pattern" and minimize the effects of size increases or changes. The radiographic cephalometric method makes it possible to describe the three-dimensional characters of the skull on a roentgenogram that presents a two-dimensional image. Thus the morphometric traits of the skull superstructures and intracranial structures are easily assessed. This enables us to use them as morphometric variables.

Future Study

We obtained much greater reliability of sex determination from skulls with perfect accuracy in this work with radiographic cephalometry and discriminant analysis. In future work, the same research methods would be applied to radiographic cephalometry of the skulls in another test samples of Taiwanese and other ethnic groups to confirm the reliability of the model of sex assignment.

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