Discriminant function analysis of foramen magnum variables in south Indian population

Vinutha S. P.[1,*], **Shubha R.**[2]

[1]Assistant Professor, JSS Medical College, Sri Shivaratheeshwara Nagar, Mysuru, Karnataka, [2]Professor, Dept. of Anatomy, Kempegowda Institute of Medical Sciences, Bengaluru, Karnataka

***Corresponding Author:**
Email: drvinutha.sp@gmail.com

Abstract

Introduction: The foramen magnum is a fundamental component in the interaction of bony, ligamentous and muscular structures composing the craniovertebral junction. All the variables were evaluated by using multivariate discriminant function analysis. This multivariate analysis is concerned with problem of assigning the individual values to a particular group, which depends on the summation of number of variable characteristics of an individual, giving equal weightage to all the characters.

Methods: The study sample comprised of 200 skull bones (105 males and 95 females) of south Indian origin. Multivariate discriminant function analysis was employed to analyze sex differences between the skull bones. The principle behind multivariate linear discriminant function is that sex is a dependent variable and measured variables are independent variables.

Results: It was noticed that out of 105, 95 male skull bones were sexed correctly and out of 95, 84 female skull bones were sexed correctly. Out of 200 skull bones, 179 skull bones were sexed correctly. So the percentage of skull bones which were sexed correctly for male was 90% and for female, it was 88%. With all the variables in consideration, overall 90% of skull bones were sexed correctly.

Conclusion: When the results of routine statistical methods and multivariate analysis were compared, it was clear that multivariate analysis was much better both in reliability and accuracy. Therefore, the multivariate analysis is the best method for determination of sex of skull bones with available resources.

Keywords: Foramen Magnum, Multivariate Analysis, Discriminant Function.

Introduction

Morphometry is the quick and efficient method for the evaluation of morphological characteristics like age, gender, ethnicity, genetic factors, food habits and geographical variations, which can alter the shape and size of bone structures. These aspects are very important for determining the anthropometric changes among different populations and genders. Base of the skull is covered by enormous amount of soft tissue, which helps to protect the foramen magnum(FM). So in cases of severe trauma, fire explosions, mass disasters etc. an intact foramen magnum morphometry helps to identify the gender and thereby identification of a person during the forensic and anthropological investigations.(1)

The degree of sexual dimorphism within the foramen magnum dimensions can be understood by its development. Compared to the other skeletal elements, the foramen magnum reaches its adult size little early in childhood and does not respond to significant secondary sexual changes. There are no muscles act on the shape and size of the foramen magnum. Its important function is to accommodate the passage of structures through the cranial base region particularly the medulla oblongata, which occupies the major proportion of the foramen magnum space. As the nervous system is the most important of all the body systems, it reaches maturity at a very early age. Therefore, this has no requirement to increase in size. This is supported by the completion of fusion of the many elements of the occipital bone by 5-7 years of age.(2)

To recognize the dead person from bones is the most important and critical problem to the anatomists, forensic science experts and anthropologist. Earlier traditional studies conducted by various authors by using non-metrical methods were centered on morphological traits, which were not reliable. Because those features depend on occupation, nutrition, race, geographical regions and visual impressions which changes from person to person. Thereafter, the trends changed to morphometry and statistical methods like univariate analysis, demarcating point and use of indices. In these methods many parameters show overlap between male and female values. Therefore, the bones cannot be sexed accurately with 100%. The recent trend is to apply advanced analytical methods to the metrical data. As quoted by the authors, sexing can be done with almost 100% accuracy, as described by Armitage by using multivariate linear discriminant functional analysis.(3)

Materials and Methods

The study sample comprised of 200 adult skull bones (105 males and 95 females) of known sex available in the Department of Anatomy, Kempegowda Institute of Medical Sciences, Bengaluru. Adult skull bones with complete FM were included in the study, whereas skull bones with damaged FM, when associated with pathological conditions and those skull bones whose sexing cannot be done were excluded from the study.

The maximum anteroposterior diameter (APD) was measured from the basion (the midpoint of the anterior margin of the FM) to the opisthion (the midpoint of the posterior margin of the FM). The maximum transverse diameter (TD) was measured between the lateral margins of the FM at the point of greatest lateral curvature. The APD and TD were measured with vernier sliding calipers. The circumference (C) was measured by pressing a narrow strip of paper along the inner margin of the FM; the paper strip was then unrolled and measured with sliding calipers (Fig 1). All measurements were recorded to an accuracy of 0.1 mm.

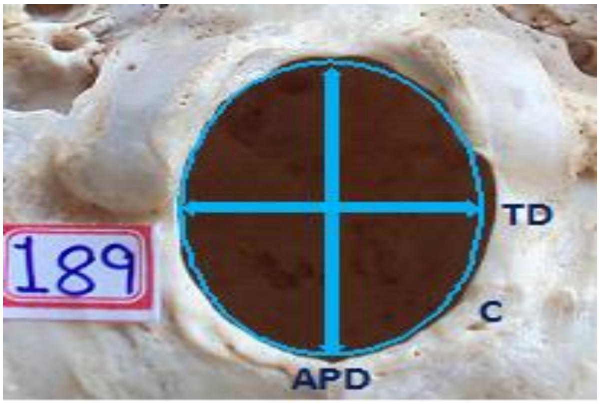

Fig. 1: Cranial base demonstrating the foramen magnum measurements

The area of the FM was calculated using 3 different formulas based on the study by Macaluso et al.(4)

1) Routal et al. formula based on the height and width of the foramen magnum
   $A = \frac{1}{4} \times \pi \times w \times h$
2) Teixeira et al. formula based on the height and width of the foramen magnum
   $A = \pi \times \{(h + w)/4\}^{(2)}$
3) Gapert et al. formula uses the circumference to estimate the radius of the foramen magnum, assuming it to be circular. This radius is then applied to the formula of the area of the circle.
   $r = c/2\pi$ and $A = \pi r^2$

Wilk's lambda is used in an ANOVA (F) test of mean differences in discriminant analysis. So, smaller the lambda for an independent variable, the more that variable contributes to its discriminant function. Lambda varies from 0 to 1, with 0 meaning group means differ and 1 meaning all group means are the same. The value nearer to zero discriminates more between males and females. The F test of Wilk's lambda shows which variable contributions are significant.

Multivariate discriminant function analysis was used to analyze sex differences within the skulls. The principle of multivariate linear discriminant function is that measured variables are taken as independent variables where as sex is a dependent variable. The discriminant function was built by assigning a discriminant score to each group. The sectioning point was created by using the mean male and female discriminant scores, which is also called as the group centroids.

After obtaining the measurements of the study and analyzing the same by computer SPSS programme, coefficients were obtained. Unstandardised discriminant coefficients were used for building the formula. The standardized (Fisher's) coefficients were used to compare the relative importance of the independent variables. The discriminant functional score (D) was obtained by summing the independent variables after weighing each of them by appropriate coefficient.

The formula was D = b0 + b1X1 + b2 X2 + – – - – – - – - + b16 X16 (b0 - constant, b1 – b16 are coefficients, X1 – X16 are variable of parameters). In the above formula, mean values of respective male and female variables were used. The functional score was designated as D_m for male and D_f for female respectively. Sectioning point (D_0) was obtained by putting the average value of mean of male and female variables in place of X. A value more than sectioning point was considered to be male, while a value lower than sectioning point was considered to be female.

Results

Below is the tabular representation of discriminant function analysis of various parameters studied in skull bones based on different gender (Table 1).

Table 1: Discriminant analysis using FM measurements in skull bones

Variable	Male		Female		Wilk's λ	F	P-Value
	Mean	S.D	Mean	S.D			
APD (mm)	33.37	2.33	29.72	1.89	0.575	146.334	<0.001*
TD (mm)	27.40	2.44	24.73	2.05	0.740	69.477	<0.001*
Circumference (mm)	102.58	4.68	92.65	4.37	0.453	239.222	<0.001*
Area 1 (mm^2)	718.41	83.75	577.52	64.36	0.531	175.169	<0.001*
Area 2 (mm^2)	727.50	83.12	583.71	63.58	0.516	185.866	<0.001*
Area 3 (mm^2)	838.77	75.94	684.36	64.10	0.453	238.809	<0.001*

*denotes a significant factor

We notice that each variable is a significant predictor in sexing a given sample (P<0.001).

In our study of skull bones, FM circumference (Wilk's lambda = 0.453, F =239.222) was the best discriminator followed by FM area 3 (Wilk's lambda = 0.453, F = 238.809). For other variables, Wilk's lambda and F value are shown in the (Table 1).

Table 2: Standardized and Unstandardized co-efficients in original sample of skull bones

Variable	Unstandardized Co-efficients	Standardized Co-efficients	Structure Co-efficients
Anteroposterior Diameter	0.307	0.656	0.727
Transverse Diameter	0.302	0.684	0.501
Circumference	0.019	0.085	0.930
Area 1	-0.061	-4.575	0.795
Area 2	0.053	3.935	0.819
Area 3	0.008	0.555	0.929
Constant	-20.657	---	---

Table 3: Linear Discriminant Function for skull bones

Variable	Male	Female
Constant	-16922.847	-16874.317
Anteroposterior Diameter	18.342	17.617
Transverse Diameter	15.821	15.110
Circumference	680.097	680.053
Area 1	0.920	1.063
Area 2	-1.341	-1.466
Area 3	-43.697	-43.715
Group Centroids	1.119	-1.237

For classifying a given sample as male or female, the higher/maximum value of following two equations are considered:

D_M**:** -16922.847 + 18.342 (Anteroposterior diameter) + 15.821 (Transverse Diameter) + 680.097(Circumference) + 0.920 (Area 1) -1.341 (Area 2) - 43.697 (Area 3)

D_F**:** -16874.317 + 17.617 (Anteroposterior diameter) + 15.110 (Transverse Diameter) + 680.053 (Circumference) + 1.063 (Area 1) -1.466 (Area 2) - 43.715 (Area 3)

By multivariate analysis, the mean functional score for male ($D_{M:}$ 1.119) and female ($D_{F:}$ -1.237) was obtained by subjecting mean values of all variables to discriminant function.

Table 4: Gender prediction accuracy in case of skull bones

True Group	Predicted Group Membership		Total	% Accurate (Overall)	% Accurate (Male)	% Accurate (Female)
	Male	Female				
Male	95	10	105	90%	90%	88%
Female	11	84	95			

It was observed that 95 male crania out of 105 were sexed correctly and 84 female crania out of 95 were sexed correctly. Overall 179 out of 200 crania were sexed correctly. So the percentage of crania which were sexed correctly for male was 90% and for female it was 88%. With all the variables in consideration, overall 90% of crania were sexed correctly (Table 4).

Discussion

The weight of the head is distributed through the atlanto-occipital region of the foramen magnum. It is known that a male brain is heavier than a female brain by weight. There is a significant difference in the width of the FM in the sexes with the predominance of males over females. This difference is related to the fact that the main neurovascular bundle such as the cervical spinal cord, vertebral arteries before and after, nerves and meninges pass through the skull base. Thus, the area of foramen magnum is bigger in males due to larger structure of skeletal muscle in men. In addition, as age advances we lose muscle mass and bone structure, and thereby it justifies the larger diameter and the differences between genders.(1)

Table 5: Comparison of the percentages of discriminant analysis of skull bones

Authors	Male (%)	Female (%)	Overall (%)
Holland et al, 1986	-	-	71-90
Wescott et al, 2001	73	79	76
Deshmukh et al, 2006	90	85.29	87.84
Gapert et al, 2009	70.7	69.7	70
Suazo et al, 2009	-	-	66.5
Macaluso et al, 2011	-	-	67.6
Present study, 2012	90	88	90

In the present study, 90% of the crania were classified correctly in overall skulls. Our findings are almost similar to that of Holland et al(5) and Deshmukh et al.(6) Holland et al(5) studied pooled black and white crania of Terry collection and Deshmukh et al(6) studied Indian population. Various other studies are done by different authors on different population. But our results are higher than most of all the other authors. This may be because of larger sample size in our study (n = 200) (Table 5). Higher the accuracy percentage of sexing obtained by multivariate analysis indicates that the studied parameters have better reliability and accuracy.

This study consists of 192 adult human skeletons of 18th and 19th century documented skeletal collection from St. Bride's Church, London. Out of 192 adult skeletons, 158 (82 males and 76 females) were employed for the determination of sex differences in the foramen magnum. The reduced number of skull bones was due to missing, badly damaged and pathological skull bases.

In their study, the variables of the foramen magnum were evaluated using both discriminant analysis and linear regression. The results show that significant sexual dimorphism is present in the cranial base. The correctly classified skull bones varied from 65.8% for univariate functions to 70.3% for multivariate functions among the skull bones sample. Males were correctly classified in 70.7% and females in 69.7% using multivariate function analysis. The linear regression equations predicted sex in the cranial sample correctly in 76% of males and 70% of females. The most reliable variable for sex determination was the width (65.8% accuracy) followed by area (65.2%) and circumference (64.6%). The best combined variables were width and circumference (70.3%). The single variables in the regression equations depict the male sex and the combined variables depict the female sex. The multivariate discriminant function analysis is the best, as it predicts both sexes equally well.

Therefore, it is important to know the original source population of any unidentified skull and choose a method based on the data from the population. The authors opined that overall expression of degree of sexual dimorphism within the foramen magnum in the present modern population is limited to 70%.(2)

This study was carried to assess the presence of sexual dimorphism in the foramen magnum size. The sample compromised of 211 human skulls (144 male skulls and 71 female skulls). Using the software, the differences between gender were analyzed by student's t- test and considered significant ($p<0.05$). Discriminant function analysis of the Fisher linear function showed that the dimensions of the foramen magnum were found to be higher in male skulls; the foramen magnum had low discriminating power and was accurately classified only in 66.5% skulls.

The accuracy in the classification is lower than those reported for majority of sexual dimorphism. Hence, morphological indicators for the occipital bone and indexes and tables of the expected range of foramen magnum dimensions in male and female skulls should be used as a first approximation to the diagnosis of sex. The authors opined that the classification of skull bones based on sexual dimorphism is more accurate when the quantitative indicator is combined with qualitative features of the occipital bone.(7)

Sectioning point analysis was carried to differentiate the sex from anteroposterior, transverse diameter and area of FM. For the dimensions and area of FM, average of mean values in males and females was taken as cut off value for sex determination and termed as the 'sectioning point'. To find the accuracy of sectioning points in sex determination, sensitivity and specificity was derived for each parameter by cross tabulation. Based on these findings the accuracy of sex determination is more with the area of FM followed by length and breadth of FM in decreasing order.

The difference in findings of the authors study from the previous studies could be attributed to methodology of recording the measurements. The authors employed different technique of measuring FM, as the availability of sophisticated CT is a premium in our country. The observations made justify the data compiled for a certain population cannot be employed for determining sex in another population.

The authors concluded that FM is a valuable tool for sex determination and can be employed with reasonable accuracy in the Indian population especially in circumstances where only skull fragments are available. The authors recommended similar studies for different and larger populations to define more accurate and reliable sectioning points for sexing foramen magnum.(8)

This study was done to establish population specific standards for sex determination from the cranium by univariate and multivariate analysis and compare the results of both of them. 16 parameters were studied on 74 adult crania of known sex (40 males and 34 females). All the crania were dry, free of any damage or deformity and were fully ossified. Foramen magnum length and breadth were measured and analyzed by routine statistical methods. The values of range, mean, standard deviation were obtained for each parameter. The t-test was applied to each parameter. Demarcating points were calculated from mean ± 3 S.D. for each parameter. Percentage of the crania identified by Demarcating point was calculated.

The amount of information lost in univariate analysis is enormous. Armitage (1971) described one important method "multivariate linear discriminant functional analysis". Discriminant functions are derived from this data, which are most efficient in differentiating the two groups and thus, minimizing errors in classifying individuals. Multivariate discriminant is more useful and productive than single discriminant function. When many variables are taken into account, some of them are significant in identifying the sex of individual and other variables by themselves may not be significant to correctly sex the individual. Any one variable may not accurately inform about the sex in 100% cases, but there are about 10-15% cases which remain without proper sex determination. Those variables are significant by themselves may potentiate the effect of other insignificant variable. If all the variables are used to determine the sex by discriminant function analysis the percentage of correct sexing still increases.

By multivariate analysis the authors found 87.84% accuracy in sexing the crania correctly. Hanihara worked on Japanese skull and found 89.7% accuracy in diagnosing the sex correctly. Giles and Elliot obtained 85.5% accuracy in sexing the crania correctly. Hong Wei Song found accurate sex determination in 96.7% of cases. Maryna Steyn found 86% accuracy in the crania by multivariate analysis. The findings of this study were almost similar to those of previous workers.(6)

The main purpose of this study is to investigate the reliability of sex and ancestry estimation using the condylar region of the occipital bone and to examine the effect of age and ancestry on the estimation of sex. This study included 389 white and 133 black adult crania (20 to 80 years of age) from the Terry and Hamann-Todd anatomical cadaver collections. The MANOVA (multivariate analysis of variance) procedure evaluates the relationship of the continuous variables to the independent classification variables. Discriminant function analysis was used to evaluate the effectiveness of the occipital bone at estimating sex and ancestry, and a stepwise procedure was used for variable selection. The stepwise procedure selects a subset of variables that has the greatest amount of discriminating ability. FM length and FM breadth are the most reliable measurements.

Measurements of the cranial base also appear to only moderately estimate sex and ancestry. Neither sex nor ancestry can be correctly classified with more than about 76% accuracy using this anatomical region. Williams used Holland's cranial base measurements to estimate sex in an archaeological sample of Arikara from South Dakota. She used 149 crania as a calibration sample to develop discriminant functions. She then used these functions to estimate the sex for calibration sample and an additional "test" sample composed of 26 crania. Sex was estimated for the "test" sample using standard cranial features. Williams found that the functions she developed using the Arikara could correctly classify sex in 76% of calibration sample and in only 58% of test sample. She also tested the functions developed by Holland on Arikara sample and observed that sex could only be correctly classified with 52% accuracy, barely better than random assignment.

The authors concluded that Holland's models provide a moderately accurate method for the estimation of sex and ancestry using fragmentary crania, but should be used with caution. The dimensions used by Holland are inconsistently defined and difficult to measure with precision. Also, neither sex nor ancestry can be estimated with more than about 76% accuracy, and this accuracy may be reduced in recent forensic cases due to secular change. The authors recommend that measurements of the cranial base may not be used for the estimation of sex or ancestry if other methods can be employed.(9)

Conclusion

When the results of usual statistical method and multivariate analysis were compared, it was obvious that multivariate analysis surpasses the former both in reliability and accuracy. Therefore, the multivariate analysis is by far the best method for determination of sex of cranium with available resources.

References

1. Manoel C, Prado FB, Caria PHF, Groppo FC. Morphometric analysis of the foramen magnum in human skills of Brazilian individuals: its relation to gender. Brazilian Journal of Morphologic sciences. 2009;26(2):104-108.
2. Gapert R, Black S, Last J. Sex determination from the foramen magnum: discriminant function analysis in an eighteenth and nineteenth century British sample. International Journal of Legal Medicine. 2009;123:25-33.
3. Deshmukh AG, Devershi DB. Comparison of Cranial Sex Determination by Univariate and Multivariate Analysis. Journal of the Anatomical Society of India. 2006;55(2):48-51.
4. Macaluso PJ. Metric sex determination from the basal region of the occipital bone in a documented French sample. Bull. Mem. Soc. Anthropol. Paris. 2011;23:19-26.
5. Holland TD. Sex Determination of Fragmentary Crania by Analysis of the Cranial Base. American Journal of Physical Anthropology. 1986;70:203-208.
6. Deshmukh AG, Devershi DB. Comparison of Cranial Sex Determination by Univariate and Multivariate Analysis. Journal of the Anatomical Society of India. 2006;55(2):48-51.
7. Galdames ICS, Russo PP, Matamala DAZ, Smith RL. Sexual Dimorphism in the Foramen Magnum Dimensions. International Journal of Morphology. 2009;27(1):21-23.

8. Babu Raghavendra YP, Manjunath S, Prateek R, Kumar Mohan TS, Janardhan BV, Yoganarasimha K, et al. Determination of Sex by Foramen Magnum Morphometry in South Indian Population. Indian Journal of Forensic Medicine and Pathology. 2011;4(1):29-33.
9. Wescott DJ, Moore-Jansen PH. Metric Variation in the Human Occipital Bone: Forensic Anthropological Applications. Journal of Forensic Sciences. 2001;46(5):1159-1163.