Sex Determination by Evaluation of Foramen Magnum on Computer Tomography Scanning Among Sri Lankan Population

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Abstract
Introduction: Sex determination using human skeletal remains is a challenging task for forensic practitioners and foramen magnum is used at lesser extents for this purpose. The aim of this study was to determine the sex by evaluating the parameters of the foramen magnum in a Sri Lankan population using computed tomography (CT).

Methods: CT images of 300 individuals aged between 20 to 60 years, comprising 146 males (49%) and 154 females (51%), obtained from the Radiology Department of National Hospital, Kandy, Sri Lanka were retrieved for the study. Four parameters of the foramen magnum, namely length, width, circumference, and area, were measured/calculated using the RadiAnt Dicom Viewer 2022.1 software and analyzed using SPSS 26 software.

Results: The analyses indicated that all four measurements were significantly higher in males than in females. All the parameters showed positive correlations with each other. Discriminant function analysis indicated that length was the most dimorphic single parameter for males, with an accuracy of 76%, and for females, the length also provided an accuracy of 71%.

Conclusion: Results of this study show that the parameters of the foramen magnum, mainly the length, can be used for sex determination. By combining other parameters of sexing human bones, more accurate results for sex determination can be obtained.

Keywords: Computed tomography; Foramen magnum; Forensic anthropology; Sri Lanka; X-ray

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Introduction

In Sri Lanka, the identification of unknown deaths and skeletal remains is one of the responsibilities of forensic pathologists and the determination of the sex of the remains is an important factor in identification. In the human skeleton, obvious sex-specific changes appear following puberty, and in adult skeletons, such changes are prominent, mainly in the pelvis and skull. Apart from these, the femur can be used for sex determination. Other than that sternum, scapula, humerus, radius, and ulnar can be considered, but they provide only a little assistance in determining the sex of an individual.[1]

The features in the human skull are helpful in determining sex, develop after puberty, and are modified by senility as well. Ancestry also has a profound effect on this matter. These differences are described for the Caucasian population and in consideration of subjects from the Indian subcontinent; osteological sex difference markers are less marked.

There are accepted markers in the human skull used in the determination of sex.[1,2] The general appearance of the skull as the female skull is rounder and smoother than the male skull and the size of the skull as the male skull is larger. Muscle ridges of the skull are more marked in the male skull, especially in the occipital area, temporal and masseter areas. In the male skull, the supraorbital ridges are more marked, and the mastoid process is larger. The frontal and parietal eminences are more prominent in female skulls. The palate is larger and more regular u-shaped in male while in female it is smaller and tend to be parabolic. Orbits are lower set, more square-shaped, and with less sharp edges in the male skull while the glabella is more marked in males. The nasal aperture is higher and narrower in the male skull with sharper edges. Also, the nasal bones are higher and project further forward to meet at an acute angle than the female in a male skull. The posterior ridge of zygomatic processes projects beyond the external auditory meatus in the male skull with zygomatic arches bowing outward more than the female. In addition, the forehead is high and steep in the female skull with a more rounded infantile contour than the male.

When considering the mandible, the male counterpart is larger, with a squarer symphysis region. The vertical height at the symphysis is greater in males and the angle of the mandible (between body and ramus) is more upright with larger condyles in males. Also, condyles are larger and border ascending ramus and a more prominent coronoid process in males. Due to the variation of the features considering a single factor alone is less advisable in consideration of the determination of sex in an adult skull.

The Latin word “foro” means bore or hole while “magnum” means great. In that sense, foramen magnum means ‘great hole’. As it is the largest foramen of the skull located on the skull base and in a center where it is covered by several groups of muscle from the inferior side, the foramen magnum is relatively resistant to traumatic injuries.

The degree of expression of sexual dimorphism within the foramen magnum dimensions may be explained by its development. Compared to many other skeletal elements, the foramen magnum reaches its adult size rather early in childhood and is therefore unlikely to respond to significant secondary sexual changes.[1] From a biomechanical viewpoint, no muscles act upon the shape and size of the foramen magnum, and its prime function is to accommodate the passage of the structures into and out of the cranial base region, and wear and tear are not involved as no frictional forces included. As the nervous system is the most precocious of all body systems, it reaches maturity at a very young age and therefore has no requirement to increase in size

Determination of sex from a cadaver is not that difficult as the genital organs are relatively resistant to putrefaction. But extensive trauma, mutilation of the body, animal attacks, transgender individuals and etc., may cause difficulties in the identification and determination of sex. In such an occasion, radiology comes to the help of the investigator. X-ray imaging and computed tomography (CT) is valuable in such investigation and especially CT as images are sharper with a high level of precision and 3D reconstruction gives the investigator better opportunities in the investigation.

Upon surveying the available literature, many studies were found to be performed on morphometric analysis of the foramen magnum.[1-6] Out of those, many studies are on dried skull bones with only a few studies on CT scans. Although several studies were found on various populations on the Indian subcontinent, these studies were population specific.[5] No studies on sex estimation using foreman magnum dimensions on the Sri Lankan population were found.

The general objective of the study was to determine the sex by foramen magnum dimensions of the human skull using computed tomography and identify the applicability to the Sri Lankan population.

Methodology

Axial non-contrast computed tomography (NCCT) scans, conducted on individuals of the age range from 20 years to 60 years of age, were retrieved from the archives of the Radiology Department of the National Hospital, Kandy. All the CT images had been obtained from the General Electric Healthcare USA 128 CT scanner available at the hospital.

Only the scans done on Sri Lankan individuals were selected and the sex of the individuals was noted. Subjects having screened for current or prior craniofacial fractures, having congenital or acquired skeletal deformities as indicated by medical records or the imaging study itself, having medical conditions that can affect skeletal growth as mentioned on the request form, and having bone pathologies including trauma were excluded. Scans with the inadequate technical quality of the radiographs to accurately obtain all required measurements were also excluded. Only the scans with complete and clear foramen magnum visualization were considered for obtaining measurements.

The following variables were used for the measurements of the foramen magnum and measurements were obtained using the RadiAnt Dicom Viewer 2022.1 (64bit) software.

1. Length of the foramen magnum: Maximum diameter of the foramen magnum along the mid-sagittal plane measured from the end of the anterior border (the basion) and to the posterior border (the opsithion) of the foramen magnum (Fig. 1a).
2. Width of the foramen magnum: The greatest dimension of the foramen magnum along its transverse direction in a plane perpendicular to the length of the foramen magnum (Fig. 1b).
3. Circumference of the foramen magnum: Measured by measuring the length of the innermost margin of the foramen magnum as a closed polygon (Fig. 1c)
4. Area of the foramen magnum: Calculated from the above measurements using RadiAnt Dicom Viewer software (Fig. 1c).

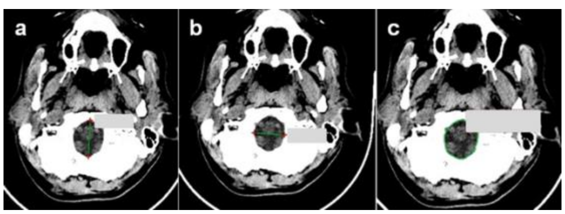

Figure 1. Parameters of foramen magnum: Maximum length (a), maximum width (b), area and circumference (c)

The collected data was entered into a Microsoft Office Excel 2010 spreadsheet and then analyzed using Statistical Package for the Social Sciences (SPSS) version 26. Student's t-test, Spearman correlation and univariate and stepwise discriminant analyses were carried out for the all-Foramen Magnum measurements.

Results

CT images of 300 individuals, with 146 males (49%) and 154 females (51%), aged between 20 to 60 years were analyzed. Table 1 presents the descriptive statistics, including means and standard deviations that were generated separately for males and females for all variables. The results indicate that the mean values of all measurements were consistently higher in males than in females. The results of the Student's t-test, which are also reported in Table 1, demonstrates highly significant differences between the sexes, with a p-value less than 0.001.

Table 1: Descriptive statistics of foramen magnum dimensions among males and females (in centimeters for length, width and circumference, and square centimeters for area)

Variable	Male (n=146)	Female (n=154)	t-value	p-value
Length	3.5138 ± 0.2340	3.2653 ± 0.2497	8.88	< 0.001
Width	2.9170 ± 0.2005	2.7393 ± 0.2233	7.24	< 0.001
Circumference	10.117 ± 0.812	9.4991 ± 0.8018	6.61	< 0.001
Area	7.9526 ± 0.9996	6.9298 ± 1.0678	8.55	< 0.001

Table 2 displays the Spearman correlation values between the measurements. The results show that all measurements had positive correlations with each other, with correlation coefficients ranging from 0.522 to 0.858.

Table 2: Correlation of the measurements (n=300)

Variables	Spearman Correlation	95% CI for ρ	p-value
Width vs. Length	0.522	(0.428, 0.604)	<0.001
Circumference vs. Length	0.795	(0.742, 0.839)	<0.001
Area vs. Length	0.801	(0.749, 0.843)	<0.001
Circumference vs. Width	0.722	(0.655, 0.778)	<0.001
Area vs. Width	0.764	(0.705, 0.813)	<0.001
Area vs. Circumference	0.858	(0.819, 0.890)	<0.001

The univariate discriminant analysis was performed by defining the demarcation points as the midpoints between the male and female means. The demarcation points serve to classify measurements above the point as likely belonging to males (as males tend to have larger measurements) and measurements below the point as likely belonging to females.

The level of differences between the sexes was determined by calculating sexual dimorphism ratios using the following formula:

Sexual dimorphism ratio = (Male mean) × 100 / (Female mean)

Table 3 displays the sexual dimorphism ratios, demarcation points, univariate F-ratios, and their significance levels. The dimorphism index is always greater than 100, indicating that, as expected, males have larger dimensions than females. The highest value of the dimorphism index was observed in the area measurement, with a difference of 15%, while the lowest value was recorded for the width measurement, at 6%.

Table 3: Demarking points, sex dimorphism, and univariate statistics of dimensions

Variable	Demarking Point	Sex Dimorphism Ratio	Wilks' lambda	F ratio	p-value
Length	F< 3.38955<M	107.610	0.791	78.632	< 0.001
Width	F< 2.82815<M	106.487	0.850	52.208	< 0.001
Circumference	F<9.80805<M	106.505	0.872	43.739	< 0.001
Area	F< 7.44120<M	114.759	0.803	72.953	< 0.001

The analysis of sex determination based on the dimensions was performed using univariate and stepwise discriminant analysis, resulting in the creation of equations to assign sex. The stepwise discriminant function analysis was conducted using the selected measurements as independent variables to distinguish between the sexes.

The results of the univariate discriminant function analysis indicated that length was the most dimorphic single parameter for males, with an accuracy of 76% after cross-validation, and for females, the length also provided an accuracy of 71% (Table 4). The cross-validated percent of correct classifications for the dimensions ranged from 64% to 76%. The overall accuracy for male and female classifications was 76% and 71% respectively, based on the univariate discriminant function analysis of the length measurement.

Table 4: Classification accuracy for individual variables

Variable	Predicted group membership					
	Original group			Cross-validated		
	Males	Females	Average	Males	Females	Average
Length	0.760	0.712	0.736	0.760	0.712	0.736
Width	0.658	0.647	0.652	0.658	0.647	0.652
Circumference	0.699	0.641	0.669	0.699	0.641	0.669
Area	0.671	0.686	0.679	0.671	0.686	0.679

The results of the stepwise discriminant function analysis are displayed in Table 5. Out of the four variables entered into the function, only length and width were selected for the final analysis. Wilks' lambda measures the contribution of each measurement and determines the order in which the variables are entered into the function. The lambda ranges from 0 to 1, where values close to 0 indicate significant differences between the group means and values close to 1 indicate similarities between the group means. The significance of changes in the Wilks' lambda is evaluated using an F-test, and if the F-value is greater than the critical value, the variable is retained in the model. Table 5 also presents the unstandardized discriminant function coefficients and the demarcation points, which are the averages of the male and female centroids.

Table 5: Summary of stepwise discriminant function analysis, unstandardized discriminant function coefficients, and sectioning points

Variable	Wilks' lambda	F ratio	d.f	Unstandardized coefficients	Sectioning points
Length	0.791	78.632	297	3.024	-0.56
Width	0.760	46.613	297	2.070	
Constant				-16.090	

The results of the stepwise discriminant function analysis are presented in Table 5, which shows that only the Length and Width were selected as the most important variables among the four initially entered. The Wilks' Lambda measures the contribution of each variable and the significance of their change, with values close to 0 indicating distinct group means, and values close to 1 indicating similar group means. The F-test is used to determine if the variable should be kept in the model. Additionally, Table 5 presents the unstandardized discriminant function coefficients and the sectioning points.

The best multivariate equation that was created using length and width had an accuracy rate of 72% (72% for males and 69% for females) after cross-validation. The discriminant function score can be calculated by multiplying each variable by its unstandardized coefficient, adding them together, and adding the constant. A score greater than the sectioning point indicates that the individual is considered male, while a score lower than the sectioning point indicates that the individual is considered female.

Logistic regression analyses were also conducted, but as the accuracy of the logistic regression models was found to be lower compared to the results of the discriminant analysis, no further analyses using logistic regression were pursued.

Table 6 compares the means of length and width of the foramen magnum from previous studies conducted using CT and dry skulls. Only the foramen magnum measurements of length in females and width in males from the Indian study conducted by Babu et al. were slightly smaller than in the present study.

Table 1: Comparison of foramen magnum length and width among different populations (mean±SD) in millimeters

Study	Yea	Method	Origin	Length		Width	
				Female	Male	Female	Male
Catalina Herrera[10]	1987	Dry skulls	Spain	34.30±2.04	36.2±2.60	29.6±1.53	31.1±2.60
Gapert et al[4]	2008	Dry skulls	Britain	34.71±1.91	35.91±2.41	29.6±1.53	30.51±2.60
Gruber et al[11]	2009	Dry skulls	C. Europe	35.8±3.5	37.1±2.7	31.0±2.8	32.4±2.4
Galdames et al[3]	2009	Dry skulls	Brazil	35.6±2.50	36.5±2.6	29.5±1.9	30.6±2.5
Ukoha et al[15]	2011	Dry skulls	Nigeria	34.39±3.88	36.26±2.3	28.16±1.9	30.09±2.5
Natsis et al[13]	2013	Dry skulls	Greece	34.79±2.39	36.20±3.39	29.61±2.08	30.92±3.15
Uysal et al*[6]	2005	CT	Turkey	34.87±2.6	37.08±1.9	28.93±2.4	30.83±2.0
Abdel-Karim et al[8]	2015	CT	Egypt	38.75±3.5	42.17±3.7	31.38±2.0	33.98±3.4
Present study*	2023	CT	S. Lanka	32.65±2.50	35.14±2.34	27.39±2.23	29.17±2.01

*Original study measurements are in centimeters

Discussion

Estimation of sex from fragmented bony remains which is a challenging task for the forensic pathologist.[4,7] The rate of success declines when individual bones are used for the determination of sex instead of the complete skeleton. The pelvic bone provides the best chance of success followed by the skull.[8, 9] The features of the foramen magnum are lesser used in comparison with other anatomical features of the skull.

Previous studies have shown that length of the foramen magnum is larger than the width.[2-4,6,8,10-15] This finding is compatible with the current study and consistent with the shape of the foramen.

Several previous studies conducted on different populations have concluded that males have larger foramen magnum lengths and widths than females which is compatible with the findings of the current study.[2,4,9,10,13,15-17] A Brazilian study had also shown that width specifically is significantly larger in males.[18] A study on Eastern European individuals and another on the Indian population which involved the measurement of length, width, and area of foramen magnum concluded that all three parameters were significantly higher in males.[19,20]A CT study conducted on the Iraqi population revealed that the circumference and area of the foramen magnum were the best discriminant parameters for the determination of sex.[21] Another CT study conducted in Iran determined that the diameter and area of the foramen magnum had a higher accuracy in sex determination.[22] In a CT study in Egyptian population sample involving the measurements of occipital condyles and the foramen magnum length and width, males showed larger measurements than females. However, when considering the foramen magnum parameters, only the width of the foramen magnum showed a significant difference between the sexes.[8] Another Saudi Arabian study had concluded that along with occipital condylar parameters, the length, width, and area of foramen magnum can be used for sexing.[23] Interestingly a CT study in India determined that combining measurements from the foramen magnum and the occipital condyles provide higher accuracy in sex determination.[24] Furthermore, a British study conducted using dry skulls from the 18th and 19th centuries concluded that the width of the foramen magnum was the most reliable variable for sex determination.[4] A Turkish study suggested that the area of the foramen magnum is not a very useful indicator for sex identification and to be used only as a supportive finding.[25]In the present study, the male parameters were larger than that of females. In the discriminate function analysis, the length of the foramen magnum was found to be the most dimorphic single parameter for males, with a higher accuracy than for females. These findings are compatible with the results of several of the aforementioned studies.[19,20,23]

Since the main neurovascular bundle with structures that passes through the foramen magnum is larger in males, it would be contributing to larger foramen magnum parameters in males.[18] Also, the greater head weight and larger neck musculature is known to cause the increase in the expression of sexual dimorphism in males.[8]

The findings from the current study suggest that the parameters of the foramen magnum, especially the length, and width, can be used for the determination of sex. This is compatible with the findings of previous studies.[2-4,6,8,10,13,15] However there are studies that contradict the sexual dimorphism in foramen magnum.[11,25,26] Previous studies that utilized discriminant function analyses and logistic regression models have yielded results in similar range to that of the present study.[1,4,21,25]

Measurements from dry bones as well as computed tomography (CT) images have been used in studies related to sex determination using the foramen magnum. [2-4,6,8,10,11,13,15] However the comparison of measurements obtained from two different modalities would lead to variations in the measured parameters, which is noted in previous studies as well.[8]

When comparing the foramen magnum parameters of length and width with the current study (Table 6), it was noted that most of the studies have yielded greater values in their studies. Only the Indian study showed slightly lower parameters in length in females and width in males. In all other ethnicities, the length and width measurements were greater than in the present study. Apart from the ethnic variations, a possible reason for such variation would be the differences in obtaining measurements since most have utilized dry skulls where some were conducted using radiological means, and differences in statistical analyses.[2,8] It is also suggested that in ethnicities with a large genetic mix, sex determination is difficult using foramen magnum parameters.[3]Across all the previously studied ethnicities in Table 6, males have shown higher lengths and widths of the foramen magnum, which is compatible with the current study findings. Since many previous studies have considered only the length and width of the foramen magnum, future studies to analyze the other two less-frequently studied parameters – area and circumference – to assess their variations across ethnicities.

From the previous and current studies, it is noted that there may be discrepancies in measurements of foramen magnum dimensions due to factors like differences in measurement modalities and ethnicities. Therefore it is recommended to use the conclusions derived from analyzing the parameters of foramen to supplement evidence from other determinants of sex in human bones.[1,2,18,20,27,28]

A noted limitation of this was that measurements were recorded in centimeters. Also, larger study sample with subjects from areas other than Kandy and the central region of Sri Lanka is recommended.

Conclusion

The results of this study indicated that all the foramen magnum measurements were higher in males than in females and the difference between the sexes were statistically significant. All the parameters showed positive correlations with each other. Discriminant function analysis indicated that length was the most dimorphic single parameter for males, with an accuracy of 76% and for females, the length also provided an accuracy of 71%.

Disclosure statement

Conflicts of interests: The author declares that he has no conflicts of interest.

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