Determination of Sex from the Foramen Magnum using 3DCT: A Nepalese Study

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ABSTRACT

Background

Identification is of utmost importance in any medicolegal investigation with sex determination being one of the principle indicators of identity. Sexing of bones becomes easy when the skeletal remains are complete. However, the problem arises when the bones are fragmented. Many researchers have undertaken several studies in different populations to determine the sex with reasonable accuracy using numerous measurements of the skull including those of the foramen magnum.

Objective

The present study was aimed to find the sexual dimorphism of the foramen magnum in the Nepalese population by analyzing the antero-posterior length, transverse diameter and area of the foramen magnum.

Method

The antero-posterior length and transverse diameter of the foramen magnum were measured using three-dimensional computed tomography (3DCT) images of the head in a cohort of 100 Nepalese subjects. Radinsky's and Teixeria's formulae were used to calculate the area of the foramen magnum. Discriminate function analysis was used to analyze sex differences.

Result

Mean values of antero-posterior length and transverse diameter of the foramen magnum in males were higher than in females. The mean of the area calculated using Radinsky's formula was smaller than that calculated by Teixeira's formula and the areas calculated were higher in males. The measurements of the foramen magnum and the areas calculated showed significant difference ($p<0.001$) between males and females. Discriminate function analysis for the measurements of the foramen magnum and the areas calculated showed high predictability for both the sexes. Discriminate function analysis showed a maximum predictability of 75%.

Conclusion

Considering the percent of predictability of sex from the various variables related to the foramen magnum in the Nepalese population, it can be concluded that its restricted applicability in forensic investigations should be constrained to cases of fragmentary skull bases.

KEY WORDS

Foramen magnum, forensic anthropology, identification, sex determination, sexual dimorphism

INTRODUCTION

Identification is of utmost importance in cases of natural or man-made mass disasters. Identifying fresh bodies is relatively easy in contrast to identifying decomposed and skeletonized human remains. One of the principle indicators of identity is determination of sex.[1-4] Sexing of bones becomes easy when the skeletal remains are complete. However, the problem arises when the bones are fragmented and incomplete. The human skull is considered as one of the most reliable bones for sex determination.[1,2]

Sex determination of the skull is primarily based on differences in the size and robusticity and is also population-specific being influenced by various factors including genetic and environmental.[3-6] Many researchers have undertaken several studies to determine the sex using numerous measurements of the skull.[7-11] Williams and Roger reported 80% accuracy of sex determination using cranial morphological traits in their study.[12] Fragmentary skulls are not uncommon in forensic practice due to either intentional destruction in an attempt to obscure facial identity or the skull being an easy target for maximum damage. Therefore, distinct regions of the skull like the mastoid process and foramen magnum have been analyzed for sex determination in different populations.[4,5] Teixeira published the first study on determination of sex from the foramen magnum.[13] Later similar studies were conducted in different populations.[14] A lack of such a study in the Nepalese population prompted us to conduct the present study with the aim of finding any sexual dimorphism of the antero-posterior length, transverse diameter and area of the foramen magnum.

METHODS

The data for the present study were collected from the Department of Radiodiagnosis and Imaging, Kathmandu University School of Medical Sciences, Dhulikhel, Nepal. This prospective study was conducted during the period extending from July 2015 to November 2015 after obtaining the ethics clearance from the aforementioned institution. One hundred Nepalese subjects (50 males and 50 females) who presented to the Department of Radiodiagnosis and Imaging for computed tomography (CT) of the head as indicated in the course of their management for diagnostic purpose were included in the present study based on convenience. Verbal informed consent was obtained from these subjects or their parents (in cases of minors) for the relevant data to be included in the present study. The measurements were taken on the console of the scanner in the Department of Radiodiagnosis and Imaging. The following dimensions of the foramen magnum were measured in centimeters using three-dimensional computed tomography (3DCT) images.

Antero-posterior length of the foramen magnum (APL): This variable was considered as the distance between the basion and opisthion based on the description in the available literature (fig. 1).

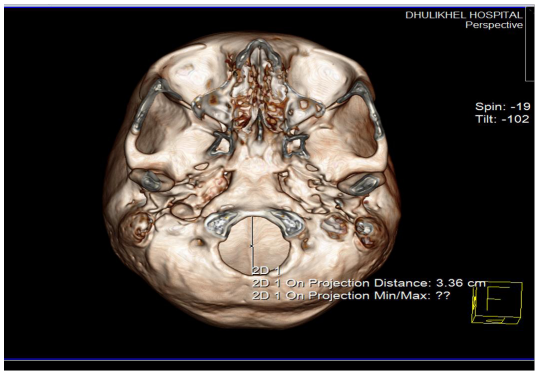

Figure 1. Antero-posterior length of the foramen magnum (APL)

Transverse diameter of the foremen magnum (TD): This variable was considered as the distance between the lateral margins of the foramen magnum at the point of the greatest lateral curvature on either side based on the description in the available literature (fig. 2).

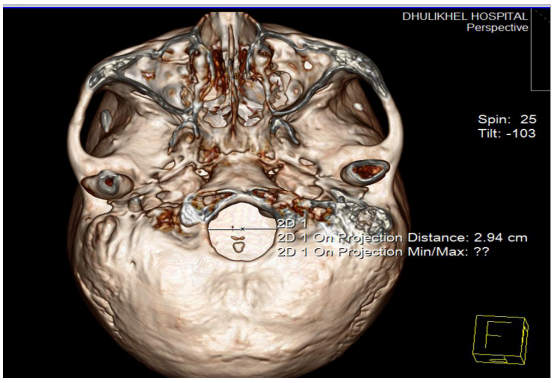

Figure 2. Transverse diameter of the foremen magnum (TD)

In addition, the area (A) of the foramen magnum was calculated using Teixeria's and Radinsky's formulae based on the available literature.

Teixeira's[13] formula: $A = \pi \times \{(APL+TD)/4\}^2$

Radinsky's[15] formula: $A = ¼ \times \pi \times TD \times APL$

The data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics Version 20. Male-female differences were tested using independent t-test and the significance level of the test was defined at α=0.05. Discriminate function analysis was used to analyze sex differences and predictability.

RESULTS

This study comprised of a total of 100 3DCT images that belonged to 50 males and 50 females of Nepalese origin. The age distribution (Table 1) for males ranged from 15 to

85 years with the mean age of 43.60(± 19.39) years and for females the age ranged from 16 to 80 years with the mean age of 42.84(± 16.63) years.

Table 1. **Age distribution of the sample**

Factors	Number	Mean	SD	Median	Min	Max	IQR
Male	50	43.6	19.38756	41.5	15	85	30
Female	50	42.84	16.63456	42.5	16	80	28
Total	100	43.22	17.97618	42	15	85	28

SD: Standard deviation; Min: Minimum; Max: Maximum; IQR: Inter-quartile range

APL and TD in males (3.43±0.26 and 2.87±0.20, respectively) were higher than in females (3.17±0.24 and 2.70±0.18, respectively). The mean of the area calculated using Radinsky's formula (AR) was smaller than that calculated by Teixeira's formula (AT), and both the areas calculated were higher in males (Table 2). The measurements of the foramen magnum and the areas calculated showed significant difference (p<0.001) between males and females.

Table 2. **Descriptive statistics of the foramen magnum according to sex**

Sex	Statistics	ALP(cm)	TD(cm)	AR	AT
Male (N = 50)					
	Mean ± SD	3.43±0.26	2.87±0.20	7.75±0.91	7.83±0.93
	Median	3.43	2.87	7.70	7.73
	Minimum	2.94	2.32	5.66	5.79
	Maximum	4.23	3.29	10.18	10.37
Female (N = 50)					
	Mean ± SD	3.17±0.24	2.70±0.18	6.75±0.84	6.81±0.85
	Median	3.11	2.69	6.59	6.61
	Minimum	2.76	2.04	4.84	5.02
	Maximum	3.82	3.10	8.83	8.92
t test value		4.967	4.435	5.685	5.693
Significance		<0.001	<0.001	<0.001	<0.001

APL: Antero-posterior length; TD: Transverse diameter; AR: Area calculated by Radinsky's formula; AT: Area calculated by Teixeira's formula; SD: Standard deviation.

Table 3 depicts the within-group correlation for all variables of the foramen magnum for both the sexes. The variables of the foramen magnum showed a strong and positive correlation (p<0.001) in both the sexes, except for the variables APL and TD (0.28) in the male sample, where the significance was less (p<0.05) when compared to the other variables.

For all the variables of the foramen magnum, stepwise discriminant function analysis was developed (Table 4). All the variables were dimorphic, and the original prediction percent of TD was 65%, APL was 67%, AR was 73% and AT was 73%.

Discriminant function analysis of all the variables was developed (Tables 5 and 6). When all the variables were used, it showed high significance (p<0.001) with canonical correlation 0.502 and Wilk's lambda 0.748.

Table 3. **Group correlation for the variables of the foramen magnum in both the sexes**

Variables	Male				Female			
	ALP	TD	AR	AT	ALP	TD	AR	AT
APL	1	0.28*	0.82**	0.86**	1	0.44**	0.87**	0.90**
TD	0.28*	1	0.78**	0.73**	0.44**	1	0.81**	0.78**
AR	0.82**	0.78**	1	0.99**	0.87**	0.81**	1	0.99**
AT	0.86**	0.73**	0.99**	1	0.90**	0.78**	0.99**	1

APL: Antero-posterior length; TD: Transverse diameter; AR: Area calculated by Radinsky's formula; AT: Area calculated by Teixeira's formula; * p<0.05; **p<0.01

Table 4. **Stepwise discriminant function analysis for sex determination from the foramen magnum**

Variables	Eigen value	Canonical correlation	Wilk's lambda	Chi-square	df	p value
APL	0.252	0.448	0.799	21.89	1	<0.001
TD	0.201	0.409	0.833	17.84	1	<0.001
AR	0.33	0.498	0.752	27.79	1	<0.001
AT	0.331	0.498	0.751	27.85	1	<0.001

APL: Antero-posterior length; TD: Transverse diameter; AR: Area calculated by Radinsky's formula; AT: Area calculated by Teixeira's formula

Table 5. **Discriminate function analysis for all the variables of the foramen magnum**

Variables	Standardized Coefficient	Structure Matrix	Centroid	Constant
APL	2.054	0.864	Male = 0.575	-32.477
TD	1.531	0.772	Female = -0.575	
AT	-1.975	0.991		

APL: Antero-posterior length; TD: Transverse diameter; AT:Area calculated by Teixeira's formula.

Table 6. **Discriminate function analysis for all the variables of the foramen magnum**

Eigen Value	Canonical correlation	Wilk's Lambda	Chi-square	Df	p value
0.337	0.502	0.748	28.027	3	<0.001

When all the variables of the foramen magnum except AR were used in combination the predictability marginally increased to 75%, in comparison to a single variable of the foramen magnum.

DISCUSSION

Several studies in the field of forensic anthropology related to sex determination from the foramen magnum have been conducted by many researchers in different populations using different methodologies ever since Teixeira's publication in the American Journal of Forensic Medicine and Pathology in the year 1982.[13] The primary finding in the present Nepalese study is that the males have larger foramen magnum dimensions in comparison to the females, as the mean value of all the measurements of the foramen magnum and the areas of the foramen

magnum calculated was higher in males than in females, which supports the findings reported in other studies conducted by researchers such as Routal et al. and Sayee et al. in Western India and South India, respectively.[16,17] Such similar findings are not only reported in the South Asian populations, as Gunayet al. reported findings with similar outcomes in the Turkish population.[18]

The present study showed significant differences between males and females ($p<0.001$) in all the measurements of the foramen magnum and the areas of the foramen magnum calculated. A positive correlation gives an impression that the foramen magnum is a reliable tool for sex determination. This finding was also reported in a study of the foramen magnum in an 18th and 19th century British sample.[5] The only study which contradicts our findings and the findings of many other researchers is the study conducted by Deshmukh and Devershi in Western India, wherein they did not find the foramen magnum to be a reliable tool for sex determination.[19]

In the present study, AT was larger than AR similar to that reported by Gapert et al. and Babu et al.[5,20] The differences in the mean values of AR and AT may be attributed to the different methodologies employed or because Radinsky's formula was not originally derived from human data and its accuracy is unknown.[20] Both the areas of the foramen magnum (AR and AT) were found to be the most reliable (73%) variables for sex determination, followed by APL (67%) and TD (65%) when a single variable was used to predict sex. The predictability of sex from the foramen magnum marginally increased to 75% when three variables, other than AR, were used in combination. With regard to a single variable of the foramen magnum having the highest predictability, different researchers have reported different outcomes. While Uysal et al.[14] reported significant sex differences in TD in the Turkish population using 3DCT images, Gruber et al.[21] did not find sexual dimorphism in TD in the Central European dry skulls. A study in the South Indian population conducted by Babu et al.[20] reported APL as the most reliable variable for sex determination followed by the area of the foramen magnum and then TD.

The foramen magnum related observations reported in the present study vary from the observations reported by other researchers. The differences in the observations made may be attributed to the different population groups, further stressing the need for population specific morphometric data for sex determination. The foramen magnum in the Nepalese population is a reliable tool for sex determination, but using only this anatomical landmark is not recommended when the complete cranium is available due to the limited expression of sexual dimorphism. Nevertheless, in fragmented or incomplete skulls, the use of the foramen magnum as an important landmark of sexual dimorphism is recommended. A prediction percent of 73% using a single variable and 75% using multiple variables of the foramen magnum were demonstrated in the present study, thus providing a statistical guide to predict the sex of the skull in the Nepalese population.

CONCLUSION

Considering the percent of predictability of sex from the various variables related to the foramen magnum in the Nepalese population, it can be concluded that its restricted applicability in forensic investigations should be constrained to cases of fragmentary skull bases. In such cases, areas (AT and AR) of the foramen magnum are most reliable individual variables that may be applied in sexing the Nepalese skulls. The predictability of sex from the foramen magnum marginally increased to 75% when three variables, other than AR, were used in combination.

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