



(RESEARCH ARTICLE)



Morphometric analysis of foramen magnum using helical computed tomography for gender determination

Nalli Prasanth Kumar ¹, Edara Naga Priyanka ², Kolappan R ^{3,*}, Rajendran Ganesh ⁴, Rajala Sushmitha ⁵

¹ Senior Lecturer, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India.

² Senior Lecturer, Lenora Institute of Dental Sciences, Rajahmundry, Andhra Pradesh, India.

³ Siva Sakthi Dental Hospital, Tirunelveli, India.

⁴ Assistant Professor in Pediatric and Preventive Dentistry, Al Baha University, Al Baha, Saudi Arabia

⁵ Welfare Dental Clinic, Ravulapalem, India.

Publication history: Received on 15 November 2020; revised on 24 November 2020; accepted on 26 November 2020

Article DOI: <https://doi.org/10.30574/wjarr.2020.8.3.0439>

Abstract

Background: The morphometric analysis of foramen magnum (FM) plays a crucial role in forensics and paleontology in identifying the gender of the unknown skeletal fragments. However, the reliability of these parameters vary among populations and races. The present study was conducted to investigate the reliability of the four foramen magnum parameters ie, foramen magnum transverse diameter, foramen magnum sagittal diameter, foramen magnum area and foramen magnum circumference in this native population.

Methods: A total of 60 subjects belonging to both genders aged between 20 – 50 years who were undergoing computed tomography (CT) examination of head and neck region were selected for the study. The study sample comprised of 30 males in group A and 30 females in group B. The measurements were obtained from reformatted axial sections using helical CT scan. The FM sagittal diameter (FMSD) and the FM transverse diameter (FMTD) were measured by the greatest anteroposterior dimension and the greatest width of the foramen. The circumference (FMC) and the area (FMA) were obtained after tracing the bony margin of the FM on the CT image using CT workstation.

Results: Mean values of all four parameters were found to be significantly higher in males compared to female subjects ($P < 0.001$). Further, the accuracy of sex determination analyzed using the discriminant equation was 70% for males and 80% for females with overall accuracy of 75%. The predictability of gender was higher in female subjects than in male subjects.

Conclusion: The dimensions of the foramen magnum can be used in gender determination of skeletal fragments with considerable accuracy. The Helical CT scan plays a pivotal role in providing accurate dimensions of the foramen magnum that could be useful in forensic testing.

Keywords: Foramen Magnum; Helical Computed Tomography; Forensics; Discriminant Function Analysis

1. Introduction

With the advancement of technology and data collection methods, forensic odontology has advanced through the evolution of mankind [1]. Over the years, forensic odontology has been recognized as a vital science in medico-legal cases and in the identification of dead person. Gender determination plays a crucial role in medicolegal cases especially in cases of natural calamities, mass disasters or crime scenes when body is decomposed and fragmented [2]. However,

* Corresponding author: Kolappan R
Siva Sakthi Dental Hospital, Tirunelveli.

in many instances the bones are recovered either in a fragmented or incomplete state, thereby possessing a challenge in gender determination [3]. Hence there is a need for the development of reliable technique for sex determination based on the available bony elements. Based on the variations in size and robustness, human cranium has been used in sex determination [4].

Foramen magnum is the largest foramen in the skull formed by the occipital bone. Over the years, foramen magnum has gathered a lot of interest in sex determination [3,5,6]. Foramen magnum is located in a favorable anatomical position within the robust occipital bone, beneath a layer of soft tissue. The positioning of foramen magnum preserves the structure for forensic examination [4]. Evidences from various studies have demonstrated ethnic differences in the size and shape of foramen magnum due to genetic, environmental and social factors [7,8]. Further studies have also reported variations in the shape of foramen magnum in males and females [9-11]. There are few Indian studies that has reported the utility of foramen magnum in sex determination [8,12].

Currently there are various radiographic techniques that are employed in forensic practice. Radiographic examinations are usually performed as a part of forensic examination for the detection of any foreign substances or for evidence of any underlying fractures and subsequent treatment [13]. The study by Uysal and colleagues reported statistically significant difference in the length and width of right condyle and width of foramen magnum in males and females ($p < 0.001$) with 81% accuracy [14]. Further the study by Vinutha et al in South Indian population reported overall 65% to be sexed correctly using computed tomographic (CT) images of foramen magnum [12]. The study by Raghavendra Babu et al also had reported sexing predictability of 65.4% and 86.5% based on transverse and anteroposterior diameter of foramen magnum [15]. Computed tomography is commonly used in forensic analysis as it has minimal superimposition of structures thereby allowing better visualization. Though there are few studies demonstrating the accuracy of foramen magnum in Indian population, the studies involving population from this part of India (Andhra Pradesh and Telangana) are scanty. Hence this study was conducted to determine the gender by morphometric analysis of foramen magnum through helical CT scan by measuring the sagittal diameter, transverse diameter, circumference, and area of foramen magnum in a population from Telangana and Andhra Pradesh region.

2. Material and methods

The study sample consisted of 60 subjects with an age range of 20 –50 years of both genders who underwent CT examination as a part of investigative procedure for diagnosis of head and neck lesions. Patients with history of trauma, surgery or pathological lesions in the region of the foramen magnum were excluded from the study. The cranial tomographic scans of poor quality which do not clearly depict the foramen magnum were also excluded. The study protocol was approved by the institutional review board.

Helical images of the brain were obtained from the level of first cervical spine to the vertex of the skull with a FOV (Field of View) of 250 mm with a standard resolution brain algorithm. The foramen magnum measurements including the sagittal diameter, transverse diameter, circumference and area were obtained from reformatted axial sections using helical CT scan (SOMARIS/5, SYNGO CT 2012E, Siemens AG, Berlin and Munchen, 1997-2011) with 3 mm thickness, 130 kVp, 250 mAs, 512 * 512 matrix, and 1.7 s scan time. The FM sagittal diameter (FMSD) was recorded as the greatest anteroposterior dimension while the FM transverse diameter (FMTD) was recorded as the greatest width of the FM. The circumference (FMC) and the area (FMA) were automatically given after tracing the bony margin of the FM on the CT image using CT workstation. To predict the gender based on the value of selected skull measurements, discriminant analysis was used.

3. Results

A total of 60 individuals were studied (30 females and 30 males with an age range of 20–50 years). The measurements and the metric parameters from the study are depicted in table 1. All measurements were significantly greater in males than in females. Two-tailed *t*-test was performed between the mean values of the metric variables among the male and female population. The results revealed a statistically significant difference for all the variables, table 1.

In the current analysis we applied Uthman's equation for gender determination [16]. The predicted male and female determination from Uthman's equation was 50% and 0%, thereby indicating a weak correlation between Uthman's equation and its applicability to our native population.

Table 1 Gender Differences for foramen magnum measurements

Study Variables	Females			Males			
	Mean	SD	SE	Mean	SD	SE	p value
FMTD	2.9023 cm	.16141	.02947	3.2190	.27297	.04984	0.001*
FMSD	3.440667 cm	.2407020	.0439460	3.764667	.3224233	.0588662	0.001*
FMA	7.173333 sq cm	.6532377	.1192643	8.618333 sq cm	1.3209038	.2411629	0.001*
FMC	12.0723 cm	.77584	.14165	13.2893 cm	1.07987	.19716	0.001*

* Statistically significant.

FMTD: foramen magnum transverse diameter; FMSD: foramen magnum sagittal diameter; FMA: foramen magnum area; FMC: foramen magnum circumference; SD: standard deviation; SE: Standard error

Due to irrelevancy of Uthman's equation, we derived a new discriminant equation through discriminant function analysis, applicable for this native population for gender determination. The calculation of accuracy was performed by calculating canonical discriminant function analysis, and group centroids. Discriminant function analysis was done for all the 4 assessed variables of foramen magnum. Discriminant function analysis was done to predict a categorical dependent variable (grouping variable) by one or more continuous or binary independent variables (predictor variables). The group centroid was calculated which was the mean value of the discriminant score for a given category of the dependent variable. There were as many centroids as there were groups or categories. The cut-off was the mean of the two centroids.

The discriminant function formula was as follows

$$F(x) = a_1x_1 + a_2x_2 + \dots + a_nx_n + c$$

- F(x): discriminant function score
- x₁ to x_n: measured variables
- a₁ to a_n: unstandardized coefficients of each variable
- c: function's constant.

Functions at group centroids were calculated and was +0.805 for males and -0.805 for females with a cut off value of zero when all the variables were used. Discriminant functions analysis was calculated for the variables measured and it produced a sex determination accuracy of about 75%. The accuracy for sex determination using all the variables by calculated equation was 70% (21 out of 30) for males and 80% (24 out of 30) for females with overall accuracy of 75%. The predictability of gender was higher in female subjects than in male subjects.

The derived discriminant equation was as follows:

$$D = 2.446(\text{FMTD}) + 0.794(\text{FMSD}) + 0.072(\text{FMA}) + 0.389(\text{FMC}) - 15.854$$

4. Discussion

Gender determination from skeletal remains is crucial in the identification of human remains, as it halves the number of possible matches [17]. Individual bone fragments are of utmost importance in forensic person identification. Gender establishment in skeletal remains examination, especially from isolated bones is a challenging objective. Sex can be estimated with 100% accuracy using the whole skeleton, and with 98% accuracy when the skull and pelvis are used. But when the skull alone is used for sex estimation, the accuracy is 80-90% [18].

The craniofacial structures have the advantage of being composed largely of hard tissue, which is relatively indestructible. Among all the craniofacial structures, foramen magnum is found to be one of the favorable anatomical structure as it is covered by the soft tissue and skeleton of the head that protects it from direct impact thus preserving this area for forensic testing. Usually the dimensions of foramen magnum will remain constant after second decade of life and will differ in male and female. It is a three dimensional, oval or circular apertures within the basal central region of the occipital bone [19].

Gender determination from skeletal remains can be performed either by morphological assessment or metric methodologies. The metric approach is more objective and less dependent on observer experience. Its replicability is high, and it is more amenable to statistical analysis facilitating between the two groups of comparisons. However, it depends on identifiable and unambiguous osteometric landmarks [14].

Over the years, various radiological modalities from conventional to digital modalities have been utilized for imaging of the facial skeletal structures in order to predict the gender. Among all the modalities used, CT scan plays a significant role in such situations. The existing literature reveals numerous studies on dry skull using foramen magnum but very few have reported using CT scan. CT scan has minimal superimposition of structures and allows better visualization of minute differences of density [19].

In the present study four metric parameters were taken into consideration. The parameters were selected such that they were easy to identify and measure from a CT scan, the imaging modality applied in the study. Moreover the metric parameters are easily reproduced and can be applied in general population. In the present study a significant difference was observed in the values of mean FMTD among the gender. The mean FMTD in males and females subjects was 32.190 millimeters and 29.023 millimeters. Male subjects showed relatively higher values than female subjects. This is in concordance with the studies conducted by Chandramani *et al* [19], Arthi *et al* [20] and Anil *et al* [21]. This accordance signifies the ease of applicability of this metric analysis. However, the results contradicted with the studies conducted by Gagandeep *et al* [22], Santhosh *et al* [23] and Yogesh *et al* [24]. This negative correlation might be the reason of ethnic variations. Foramen magnum sagittal diameter was the next parameter considered in the study. Significant difference was observed in the values of mean foramen magnum sagittal diameter among the gender. The mean FMSD in males and females subjects was 37.64667 millimeters and 34.40667 millimeters respectively.

Foramen magnum area was another parameter taken in the study. The mean FMA in male and female subjects were 8.618333 square centimeters and 7.173333 square centimeters respectively. Male subjects showed relatively higher values than female subjects. The last parameter taken in the study was foramen magnum circumference. The mean FMC in males and female subjects were 132.893 centimeters and 120.723 centimeters respectively. Male subjects had relatively higher values than female subjects. The predicted male and female subjects from Uthman's equation was 50% and 0% respectively [16]. Hence the applicability of Uthman's equation showed weakest correlation with this native population.

The equation provided for calculating D was as follows:

$$D = -12.273 + (0.136 \times \text{FMSD}) + (0.078 \times \text{FMTD}) + (0.165 \times \text{FMC}) + (-0.008 \times \text{FMA})$$

Due to irrelevancy of Uthman's equation, we derived a new discriminant equation which was applicable to this native population for gender determination through discriminant function analysis. In the present study a stepwise analysis of the discriminant functions was calculated for the variables measured and it produced a sex determination accuracy of about 75%. The accuracy for sex determination using all the variables was 70% for males and 80% for females. The predictability of gender was higher in female subjects than in male subjects.

The derived discriminant equation was as follows:

$$D = 2.446(\text{FMTD}) + 0.794(\text{FMSD}) + 0.072(\text{FMA}) + 0.389(\text{FMC}) - 15.854$$

These accuracies were comparable to the accuracies obtained by Chandramani *et al* (76%) [12] and Deepali *et al* (75.7%) [25]. The results of our study demonstrated better accuracies compared to the studies by Gagandeep *et al* (70%) [22], Edwards K *et al* (66%) [26], Ivan Claudio *et al* (66.5%) [27] and Rene Gapert *et al* (68%) [28]. Accuracy obtained in the present study was lesser than that of the studies conducted by Uthman *et al* (81.8%) [16] and Ibrahim *et al* (90%) [18]. The variations in the accuracies can be attributed to the ethnic variations and the different imaging modalities used.

5. Conclusion

This present study produced a gender determination accuracy of about 75%. The accuracy for sex determination using all the variables by calculated equation was 70% for males and 80% for females with overall accuracy of 75%. The predictability of gender was higher in female subjects than in male subjects.

Compliance with ethical standards

Acknowledgments

We would like to thank all the subjects who participated in the study. We would also like to thank Dr Soumya M, MDS for reviewing our work and giving her valuable feedback.

Disclosure of conflict of interest

The authors report no conflict of interest in this work.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

- [1] Balachander N, Babu NA, Jimson S, Priyadharsini C, Masthan KMK. Evolution of forensic odontology: An overview. *J Pharm Bioallied Sci.* 2015; 7(Suppl 1):S176-180. doi:10.4103/0975-7406.155894
- [2] Jeddy N, Ravi S, Radhika T. Current trends in forensic odontology. *J Forensic Dent Sci.* 2017; 9(3):115-119. doi:10.4103/jfo.jfds_85_16
- [3] Sahni D, Sanjeev null, Singh G, Jit I, Singh P. Facial soft tissue thickness in northwest Indian adults. *Forensic Sci Int.* 2008; 176(2-3):137-146. doi:10.1016/j.forsciint.2007.07.012
- [4] C N Orish, B C Didia, H B Fawehinmi. Sex Determination Using Inion-Opistocranium-Asterion (IOA) Triangle in Nigerians' Skulls. *Anat Res Int.* 2014; 2014:747239.
- [5] Hend M H Abo El-Atta, Rania Hamed Abdel-Rahman, Galal El-Hawary, Heba M. Abo El-Atta. Sexual dimorphism of foramen magnum: An Egyptian study. *Egypt J Forensic Sci.* 2020; 10(1)
- [6] M-E Chovalopoulou, A Bertatos. Estimating sex of modern Greeks based on the foramen magnum region. *Journal of Anthropology.* 2017; 2017:7 pages.
- [7] M J Zdilla, M L Russell, K N Bliss, K R Mangus, A W Koons. The size and shape of the foramen magnum in man. *J Craniovertebr Junction Spine.* 2017; 8(3):205-221
- [8] N A Raikar, M A Meundi, C M David, M D Rao, S C Jogigowda. Sexual dimorphism in foramen magnum dimensions in the South Indian population. *J Forensic Dent Sci.* 2016; 8(3):180.
- [9] R Veeramani, KY Manjunath, U Amirthalingam. Morphological and Morphometric study of variations in the shape and size of the foramen magnum of human skulls. *International Journal of Anatomy, Radiology and Surgery.* 2018; 7(2):A001-A008
- [10] M P Shepur, Magi M, Nanjundappa B, P P Havaldar, P Gogi, S H Saheb. Morphometric analysis of foramen magnum. *International Journal of Anatomy and Research.* 2014; 2(1):249-55
- [11] M Moodley, C Rennie, L Lazarus, K S Satyapal. The morphometry and morphology of the foramen magnum in age and sex determination within the South African Black population utilizing computed tomography (CT) scans. *Int J Morphol.* 2019; 37(1):251-257
- [12] S P Vinutha, V Suresh, R Shubha. Discriminant function analysis of foramen magnum variables in South Indian population: A study of computerized tomographic images. *Anat Res Int.* 2018; 2018:2056291.
- [13] K Krishan, T Kanchan, A K Garg. Dental Evidence in forensic identification- An overview, methodology and present status. *Open Dent J.* 2015; 9:250-256.

- [14] S Uysal, D Gokharman, M Kacar, I Tuncbilek, U Kosa. Estimation of sex by 3D CT measurements of the foramen magnum. *J Forensic Sci.* 2005; 50(6):1310-4
- [15] Y P Raghavendra Babu, T Kanchan, Y Attiku, P N Dixit, M S Kotian. Sex estimation from foramen magnum dimensions in an Indian population. *Journal of Forensic and Legal Medicine.* 2012; 19(3):162-167
- [16] Uthman A T, Al-Rawi N H, Al-Timimi J F. Evaluation of foramen magnum in gender determination using helical CT scanning. *Dentomaxillofacial Radiology.*2012; 41:197-202.
- [17] Bidmos M A, Gibbon, Strkalj. Recent advances in sex identification of human skeletal remains in South Africa. *South African Journal of Science.*2010; 106.
- [18] Ibrahim Abdel-Karim R, Mohamed Housseini A, Kamal Hashish R. Adult sex estimation using Three Dimensional Volume Rendering Multislice Computed Tomography of the foramen magnum and occipital condyles: A study in Egyptian population. *International Journal of Advanced Research.*2015; 3(5):1212-1215.
- [19] Chandramani B, Nairita S, Ritika V. Morphological analysis of foramen magnum for gender determination by using computed tomography. *Journal of Oral Medicine, Oral Surgery, Oral Pathology and Oral Radiology.*2015; 1(2):51-56.
- [20] Arthi G, Sadeesh T, Sudha R. Morphometric analysis of foramen magnum in adult human skulls and CT images. *International Journal of Current Research and Review.* 2014; 6(20).
- [21] Anil Kumar, Mitesh D, Anwar S. Morphometric evaluation of foramen magnum in dry human skulls. *International Journal of Anatomy and Research.* 2015; 3(2):1015-23.
- [22] Gagandeep S, Indu T. Morphometric analysis of foramen magnum in human skull for sex determination Human Biology. *Human Biology Review.*2013; 29-41.
- [23] Santhosh C S, Vishwanathan K G, Ashok Gupta, Siddesh R C, Tejas J. Morphometry of the Foramen Magnum: An Important Tool in Sex determination. *Journal of Medical and Health Sciences.*2013; 2(4).
- [24] Yogesh Y, Preeti G. Study of Length and Width of Foramen Magnum in North India. *International Journal of Science and Research.*2014; 3(6).
- [25] Deepali J, Jasuja O P, Surinder N. Evaluation of foramen magnum in sex determination from human crania by using discriminant function analysis. *Elective Medicine Journal.*2014; 2
- [26] Edwards K, Viner D, Schweitzer W, Thali M J. Sex determination from the foramen magnum. *Journal of Forensic Radiology and Imaging.*2013; 186–192
- [27] Ivan Claudio S G, Priscilla P R, Daniela A, Zavando M, Ricardo L. Sexual Dimorphism in the Foramen Magnum Dimensions. *International Journal of Morphology.*2009; 27(1):21-23.
- [28] Rene G, Sue B, Jason L. Sex determination from the foramen magnum: discriminant function analysis in an eighteenth and nineteenth century British sample. *Int J Legal Med.*2009; 25–33