ORIGINAL ARTICLE

Sexual dimorphism in foramen magnum dimensions in the South Indian population: A digital submentovertex radiographic study

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Abstract

Purpose of the Study: Personal identification is a vital arena of forensic investigation, facilitating the search for missing persons. This process of identification is eased by the determination of age, sex, and ethnicity. In situations where there are fragmented and mutilated skeletal remains, sex determination is relatively difficult, and it becomes important to establish the accuracy of individual bones. **Aim:** This study aims to evaluate sexual dimorphism in foramen magnum (FM) dimensions in the South Indian population using digital submentovertex (SMV) radiograph. **Materials and Methods:** 150 individuals (75 males and 75 females) were subjected to digital SMV radiography. FM in the resultant image was assessed for longitudinal and transverse diameters, circumference, and area. Also, one particular shape was assigned to each image based on the classification of Chethan *et al.* of FM shapes. Three qualified oral radiologists performed all the measurements twice within an interval of 10 days. **Results and Conclusion:** The values obtained for all four parameters were statistically significant and higher in males than in females. The most common morphology of FM was an egg shape while hexagonal was the least common morphology. Circumference was the best indicator of sex followed by area, transverse diameter, and longitudinal diameter. Having achieved a high accuracy of 67.3% with digital SMV radiograph makes it a reliable and reproducible alternative to dry skulls for sex determination.

Key words: Area, circumference, diameter, digital submentovertex radiograph, foramen magnum

Introduction

Personal identification is the act of establishing the identity of a person—by linking him/her to the stream of data in the information systems.[1] It beholds a major portion in forensics and usually relies on the comparison of the known features to the unknown specimen.[2] Identification of an individual is vital for the family not only from an emotional standpoint but is also a medicolegal requirement.[3] In living individuals, identification plays a pivotal role in cases such as property disputes, insurance claims, issuance of passports, and various other licenses,

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whereas after death, it becomes important to identify the deceased as in case of a murdered victim, or file closure of a person missing for a prolonged period to facilitate the rituals of body disposition following death and permission of remarriage. So, the society's duty to preserve human rights and dignity beyond life begins with identity.[3] Hence, positive identification is required both for legal and humanitarian reasons.[1]

Identification of the living individual is less cumbersome since simple methods such as direct visual recognition by a family member, friend, or acquaintance is possible that is done by the identification of unique physical characteristics such as scars, birthmarks and tattoos.[1] This method of personal recognition can be applied to identify the decedent as well. However, standardized techniques such as antemortem and postmortem comparisons of fingerprints, palm prints, and footprints act as reliable tools for positive identification.[4] Nevertheless, all of these methods depend on the preservation of soft tissue components of the body in question, and cannot be applied when the surface topography is unrecognizable or featureless—as in decomposed, burnt, mutilated, skeletonized, and fragmented states. In such circumstances, identification is solely dependent on the skeletal framework of the decedent, and the process starts with the determination of age and sex.[5]

Sex determination reduces the search of individuals by 50%[6] and is 98% accurate when the whole skeleton is available.[7] But finding an intact skeleton is not always likely.[7] In such circumstances, pelvic bone possesses highest sex discriminant accuracy of 95%.[8] The skull is the second best alternative[6,8,9] and is 90% accurate[8] to determine the sex of the decedent. However, in explosions, warfare and mass disasters, human remains are often obtained in fragmented states.[6,8] In such circumstances, only strong bones that greatly resist fracture are likely to be recovered intact. Forensic investigators have thus attempted to utilize them for personal identification. The base of the skull is one such bone and establishing sex discriminant value of the skull base has attracted attention.[7,9]

Foramen magnum (FM) is an important structure of the skull base.[8] It is located inferior to the sagittal suture and surrounded by the basilar, squamous, and lateral parts of the occipital bone.[10] Situated in the deepest part of the posterior cranial fossa and covered by a large volume of soft tissue, it is an ideal structure for sex determination.[11] Sexual dimorphism in FM dimensions is population-specific and highly influenced by environmental, socioeconomic, and genetic factors.[11] This digital radiographic study aims at evaluating the accuracy of FM dimensions in sex determination of South Indian adults. The results obtained by the study would help in personal identification of the given population.

Materials and Methods

The present study was conducted on 150 South Indian subjects comprising 75 males and 75 females. The subjects chosen were in the age group of 25–65 years, randomly selected from patients of Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India. Subjects with craniofacial anomalies and syndromes or history of craniofacial surgeries were excluded. The literature suggests that the growth of the FM continues until early childhood. Hence, in order to prevent the age factor influencing the results, subjects under 25 years were not included in the study. Furthermore, patients beyond 65 years are unlikely to be in need of submentovertex (SMV) radiographs. Hence, they were excluded from the study. The radiographic procedure was explained to all the subjects and informed written consents were obtained.

Sirona (New York, U.S.A.) ORTHOPHOS XG 5 machine was prepared for the submentovertex radiographic procedure by positioning it to C2 program, which is specifically designed for anteroposterior projections. A charge-coupled device (CCD) image receptor was placed in its slot and the unit was approximated to the patient's head position [Figure 1]. Exposure parameters were personalized as per the manufacturer's recommendations during the radiographic exposure and the image was displayed on the digital display monitor.

Three qualified oral radiologists with an experience of 5–10 years evaluated the FM dimensions in the resultant image under standardized viewing conditions. During interpretation, the observers were permitted only to modify the contrast and brightness of the image (if and when required) just to facilitate the visualization of the FM boundaries. The anonymity of the subjects was maintained during every interpretation. Each observer evaluated all the 150 images twice within a minimum period of 10 days.

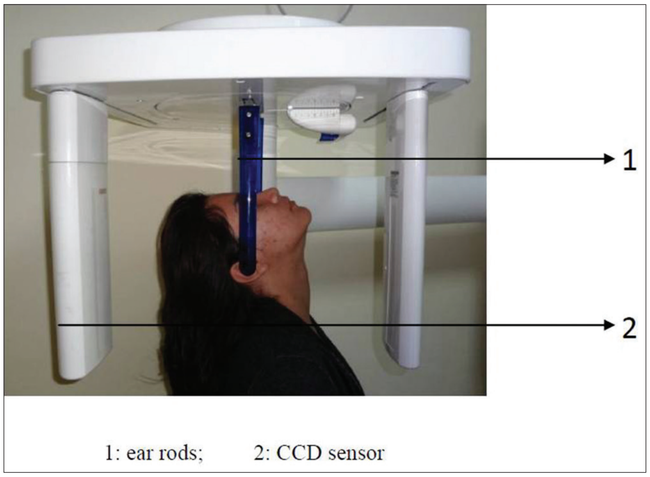


Figure 1: Patient positioned for digital submentovertex radiograph

The following measurements of the FM were recorded in millimeters [Figure 2]:

- Longitudinal diameter/length of FM (LD): Maximum anteroposterior dimension measured from the highest point on the anterior border up to the inferior-most point
- Transverse diameter/width of FM (TD): The maximum mesiodistal dimension measured from the point of highest convexity on the medial border up to the point of highest convexity on the distalmost margin
- Circumference of FM (C): Perimeter obtained by tracing the entire border of FM
- Area (A) of FM: Calculated by substituting LD and TD in Radinsky's formula
  Radinsky's formula: Area = $\frac{1}{4} \pi \times \mathrm{LD} \times \mathrm{TD}$
- Shape of FM: Subjective assignment of one of the seven shapes to FM morphology according to the classification of Chethan *et al*. of FM shapes[12] [Figure 3].

All the recordings were tabulated and subjected to the statistical analysis using Statistical Package for the Social Sciences (SPSS) software version 16.0 (Manufacturer- IBM SPSS Statistics, formerly known as SPSS Inc.). Data comparison was done by applying Student's *t*-test to find out the statistical significance of the obtained results. The level of significance was set at 0.05.

Results

The mean and standard deviation for all the four measurements were obtained to derive the FM dimensions in the South Indian population. Table 1 shows the mean values with the standard deviation for longitudinal diameter, transverse diameter, circumference, and area for 75 males and 75 females as assessed by all the three observers independently. The values for all the four parameters were higher in males as compared to females, highlighting sexual dimorphism in FM dimensions. To substantiate this, *P* value was derived by applying Student's *t*-test and it was seen that *P* value was < 0.05 for longitudinal diameter, transverse diameter, circumference, and area [Table 2]. This suggests that the difference in the mean values between males and females in all the four measurements were statistically significant.

Figure 2: Digital submentovertex image with analysis of the foramen magnum dimensions

To evaluate intra-observer agreement, *r* value (degree of correlation) was calculated for all the four FM dimensions as measured by the observers on the first day and second day of observation [Table 3]. *r* value showed a strong degree of correlation for LD, TD, and C, and a moderate degree of correlation for A, suggesting good intra-observer agreement.

To evaluate interobserver agreement, *r* value (degree of correlation) was calculated for all the four FM dimensions as measured by all the three observers. The resultant *r* value suggested a strong inter-observer agreement [Table 4].

To assess the accuracy of digital SMV radiograph, at first, a formula was derived using discriminant function analysis:

$$\text{Gender} = [(-0.275 \times \text{LD}) + (0.163 \times \text{TD}) + (0.461 \times \text{C}) + (0.677 \times \text{A})] - 104.89$$

By applying our data to the derived equation, canonical variables were derived for all the four FM dimensions.

Table 1: Sexual dimorphism in the foramen magnum dimensions

Foramen magnum dimensions	Mean values±standard deviation (mm)	
	Males	Females
Longitudinal diameter (LD)	34.19±3.57	32.49±3.17
Transverse diameter (TD)	31.77±3.59	29.66±2.71
Circumference (C)	106.15±9.65	99.95±7.72
Area (A) (mm^2)	800.72±86.85	769.93±89.58

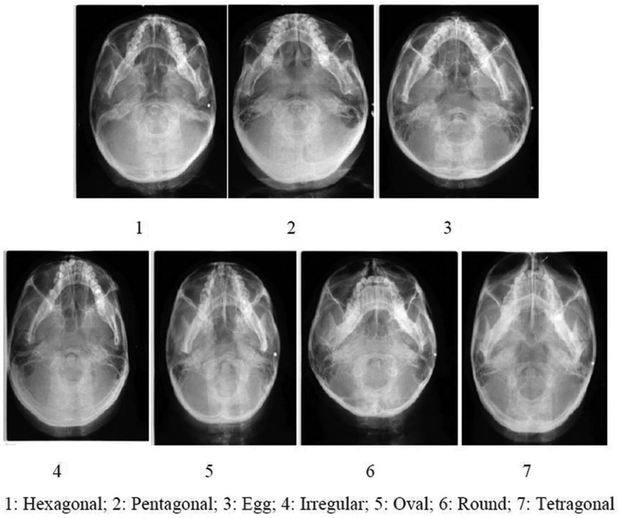


Figure 3: Seven morphometric types of foramen magnum

An accuracy of 67.3% was obtained when a total of 150 subjects were considered [Table 5]. Also, an attempt was made to assess, which among the four parameters was most efficient in sex determination. It was seen that maximum accuracy was obtained for C and the least for LD. Thus, C was the best indicator for sex determination followed by A, TD and LD.

Table 2: Foramen magnum measurements in males and females as assessed by all the three observers

Foramen magnum dimensions ($n=75$)	Three observers	Sex	Mean	Standard deviation	P value ($P<0.05$)
Longitudinal diameter (LD)	1	M	34.42	3.45	0.001*
		F	32.56	3.12	
	2	M	33.88	3.55	0.001*
		F	32.06	3.23	
	3	M	34.27	3.71	0.014*
		F	32.86	3.18	
Transverse diameter (TD)	1	M	31.82	3.69	0.001*
		F	29.40	2.72	
	2	M	31.63	3.46	0.001*
		F	29.74	2.47	
	3	M	31.85	3.62	0.001*
		F	29.85	2.94	
Circumference (C)	1	M	105.18	8.87	0.001*
		F	98.77	7.17	
	2	M	108.18	9.74	0.001*
		F	100.3	7.79	
	3	M	105.1	10.36	0.005*
		F	100.8	8.21	
Area (A)	1	M	813.75	81.36	0.0438
		F	765.33	93.58	
	2	M	786.2	89.61	0.380
		F	777.28	97.06	
	3	M	802.22	89.59	0.001*
		F	767.18	78.12	

*Statistically Significant; M: Males, F: Females

Table 3: Intra-observer correlation (r) of the foramen magnum dimensions based on the first day and the second day of observation

Observers	r value			
	Longitudinal diameter (LD)	Transverse diameter (TD)	Circumference (C)	Area (A)
1	0.849	0.896	0.861	0.533
2	0.853	0.887	0.842	0.755
3	0.823	0.869	0.863	0.687

r: degree of correlation: 1.0=perfect; 0.7±1.0=strong; 0.4±0.7=moderate; 0.2±0.4=weak; 0.01±0.2=negligible; 0.0=no association

Table 4: Inter-observer correlation (r) of the foramen magnum dimensions

Observers	r value			
	Longitudinal diameter (LD)	Transverse diameter (TD)	Circumference (C)	Area (A)
1-2	0.694	0.711	0.646	0.601
1-2	0.692	0.721	0.712	0.712
2-3	0.693	0.691	0.703	0.591

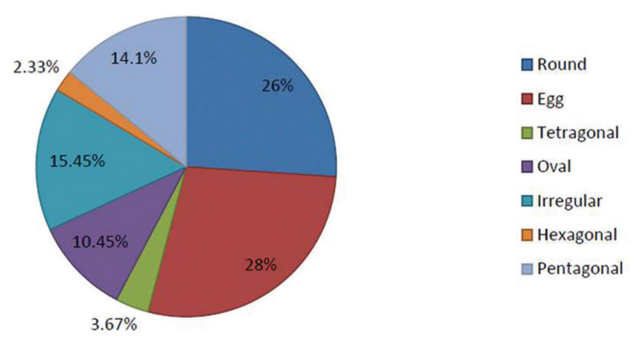
r: Degree of correlation: 1.0=perfect; 0.7±1.0=strong; 0.4±0.7=moderate; 0.2±0.4=weak; 0.01±0.2=negligible; 0.0=no association

Morphology of the FM: The shapes assigned by all three observers for a total of 150 images, as determined twice, made it a total of 900 shapes. Using the classification given by Chethan *et al*.,[12] it was observed that egg shape was the most common shape and hexagon was the least common shape [Figure 4]. Similar results were observed in the FM of males and females [Figure 5].

Discussion

Positive identification of the deceased is a very crucial aspect of forensic science and sex determination beholds a major role in this regard. Sex determination helps to channelize the investigation by deducing the search to half the population, thus conserving both resources and the time required for identification.[6] When the entire skeleton is present, sex determination is possible with 100% accuracy.[13] However, in many instances human remains are likely to be obtained in fragmented states.[8] In such situations, the pelvis has demonstrated maximum accuracy in sex determination followed by the pelvis if available with cranium,[7] pelvis with long bones, and long bones or skull in isolation.[8] The base of the skull, precisely the occipital bone is often recovered intact, even in cases of severe trauma due to its well-protected anatomical position and large amount of overlying soft tissue.[8]

FM is a vital and prominent structure of the skull base. It has been found to exhibit differences in its dimensions between males and females. But this sexual dimorphism is population-specific, as demonstrated by studies on the populations of Iraq,[8] Turkey,[7,14] Brazil,[15] Poland,[16] and Nigeria;[17] This is also seen in India in diverse geographical locations such as Uttar Pradesh,[18,19] Gujarat,[20] Chandigarh,[21] and Madhya Pradesh.[22] The dimensions of FM are also influenced by genetic, environmental, and social factors.[11,21] Taking this into account, we conducted



%: percentage; FM: Foramen Magnum

Figure 4: Pie chart depicting the distribution of the foramen magnum shapes in 150 subjects

Table 5: Accuracy of foramen magnum dimensions in sex determination

Parameter	Sex	Canonical variables	Accuracy (%)	Overall accuracy (%)
Longitudinal diameter (LD)	M	0.228	62.7	60.7
	F	−0.228	58.7	
Transverse diameter (TD)	M	0.344	64.0	62.7
	F	−0.344	61.3	
Circumference (C)	M	0.350	66.7	66.0
	F	−0.350	65.3	
Area (A)	M	0.396	62.7	64.7
	F	−0.396	66.7	
Digital SMV Radiograph	M	-	65.3	67.3
	F	-	69.3	

M: Males; F: Females; %: Percentage

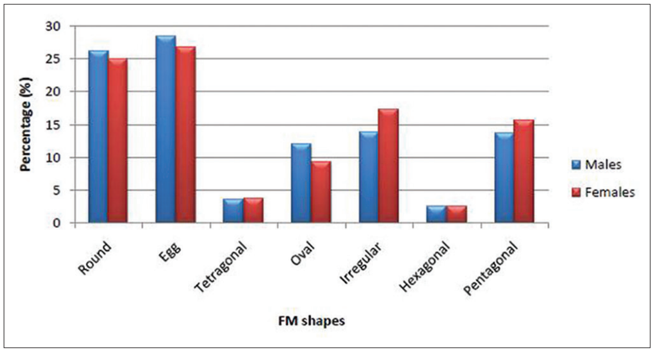


Figure 5: Bar diagram representing the distribution of the foramen magnum shapes in males and females

our study on the South Indian population. Many authors have demonstrated sexual dimorphism in the South Indian population as well[6,9-11] but they have utilized dry skulls to derive their results. This limits the study sample. Moreover, archiving skulls of a known age and sex for the study is an added drawback. To overcome this, we performed the study with the help of archived digital SMV radiographs and perhaps this is the first of its kind.

FM completes its growth by early childhood.[13] It is unresponsive to secondary sexual changes, with no influence of musculature on its size and shape, making it considerably stable beyond adolescence.[13]

The FM measurements obtained in our study clearly showed statistically significant differences between the genders (P value < 0.05) with all values significantly greater in males than in females. Babu[11] found the mean LD values to be 35.68 mm in males and 32.57 mm in females; Kanchan *et al*.[10] reported values of 34.51 mm in males and 33.6 mm in females. The mean values of TD as reported in these studies were 28.91 mm in males and 28.19 mm in females (Babu R); 27.36 mm in males and 26.74 mm in females (Kanchan *et al*.). Our obtained values using digital SMV radiograph are in accordance with those obtained on direct measurements of the skull as seen in aforementioned studies [Table 1]. This justifies that SMV can effectively replace dry skulls in the measurement of FM dimensions.

A (Area) of FM was calculated by using Radinsky's formula. In a review of the literature, we observed that researchers had used two formulae to calculate the area: Texeira formula and Radinsky's formula. Among the Indian studies, Kanchan *et al*.[10] and Babu[11] used both the formulae in their study and have opined that the value for A obtained by Radinsky's formula is a better evaluator of sex. Based on this, we chose Radinsky's formula to calculate A. The results showed statistically significant gender difference and are comparable to those obtained by Kanchan *et al*. (744.33 mm^2 in males and 706.93 mm^2 in females) and Babu R (811.67 mm^2 in males and 722.66 mm^2 in females). This is an expected result because the aforementioned studies were also conducted among subjects of Karnataka who were representative of the South Indian population.

We presume that this is the only Indian study to have assessed the C of FM. Hence, we compared the derived mean C values (males: 106.15 mm; females: 99.95 mm) with the next only available study[8] conducted on the Iraqi population by Uthman *et al*. where the mean C values was found to be 99.3 mm in males and 92.6 mm in females. Thus, our C values were in accordance to the aforementioned study.

Discriminant function analysis demonstrated that C of FM was 66% accurate and was the best predictor of sex among the four parameters, capable of differentiating males with 66.7% accuracy and females with 65.3% accuracy [Table 5]. The next best predictor of sex was the A of FM (64.7%) followed by TD (62.7%); LD (60.7%) formed the lowest predictor. The reliability of TD, LD and A in sex determination has been demonstrated with variable results by different authors, with one parameter being better over the other. The greater accuracy of C in our study brings to light that the C of FM is the most important parameter and must always be evaluated during the morphometric analysis of FM for sex determination.

We categorized the FM morphology of all the 150 subjects according to the shapes classified in the study on South Indian subjects by Chethan *et al*.[12] We found egg shape to be the most common and hexagon to be the least common [Figures 4 and 5]. Though we considered the classification of Chethan *et al*.[12] to categorize the shapes, the incidence of occurrence in their study showed slight variations from ours, with round being the commonest shape followed by egg and tetragonal shape. But the incidence rate of round shape in their study (22.6%) is similar to the incidence rate in our study. By this, we opine that in the South Indian population, the FM commonly exhibits a round or egg shape.

A high degree of inter-observer correlation [Table 4] implies that FM dimensions are minimally affected by subjective variations and hence, are highly reproducible in establishing sexual dimorphism. Strong degrees of correlation for LD, TD, and C and a moderate degree of correlation for A achieved by comparing the values obtained on the 2 days of observations by each observer suggest moderate to strong intra-observer association. The inference is that FM dimensions are less likely to vary on repeated measurements. This strengthens the hypothesis that digital SMV radiograph can effectively be used to establish sexual dimorphism in FM.

By applying discriminant function analysis, it was seen FM dimensions evaluated using digital SMV radiograph were 67.3% accurate in differentiating sex and 65.3% and 69.3% accurate in determining males and females, respectively [Table 5]. Our results are similar to the accuracy rate achieved by measuring FM dimensions on dry skulls by Suazo *et al*.[15] (66.5%), Texeira (70%), and Gapert *et al*.[23] (70.3%) in the expression of sexual dimorphism. Thus, we opine that digital SMV radiograph can be an excellent alternative to direct morphometry in evaluating sexual dimorphism using FM dimensions.

However, the accuracy achieved by using SMV radiographs is lower than the accuracy (81%) achieved in the study by Uysal *et al*.[7] on computed tomography (CT) images. In CT, though a contrast between the anatomical structures is enhanced, the greatest disadvantage is its high radiation dose to the patients (20 µSv), which is 4–77 times higher[23] than for the digital SMV radiograph (0.6 µSv). Achieving an accuracy of 67.3% at a reduced radiation exposure, digital SMV can readily replace the use of CT scan in evaluating FM dimensions.

The results of our study demonstrate that all the dimensions (LD, TD, C and A) are higher in males than in females, with the values being similar to the studies performed earlier by direct morphometry or CT. C is the best predictor of sex with maximum accuracy. Strong intra- and inter-observer agreements between the values of FM dimensions emphasize that digital SMV radiograph is efficient for measuring FM dimensions and can be a good alternative to dry skulls and CT for sex determination.

Conclusion

FM offers a valuable tool in studying sexual dimorphism. Our study elucidates its morphometric data and variations in the morphology with emphasis on its application in the identification of unknown individuals. We believe that data obtained from our study will be useful to forensic investigators, anthropologists, clinical anatomists and the neurosurgeons. FM dimensions are population-specific; therefore, values derived from the respective population must be considered during evaluation of FM of unidentified skull remains. The C and A of the FM in South Indian adults are useful indicators of sex. Yet considering the limited accuracy rate achieved by the study, the application of FM in sex determination should be restricted to cases where only a fragment of the skull base is brought for examination and should not be used in a situation where the complete cranium is present; wherein other reliable skull parameters can be used.

To the best of our knowledge, this is the first study to make use of digital SMV radiograph to establish sexual dimorphism in FM. Achieving a fair accuracy rate, we emphasize that digital SMV radiograph can be a promising alternative to CT, offering reduced radiation exposure to the patient at an affordable price.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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