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Stature Estimation from Postmortem Multidetector Computed Tomography (PMCT) Foramen Magnum Measurements in North Indian Population

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Abstract

Background: The present study is an attempt to estimate stature from the measurements of Foramen Magnum using postmortem multidetector computed tomography (PMCT) in the North Indian population. Foramen Magnum Length (FML) and Foramen Magnum Breadth (FMB) measurements for every skull were taken using the PMCT of 100 North Indian people.

Materials and Method: PMCT examination was performed using a 16-slice MSCT spiral scanner, Cannon Medical Systems, results were evaluated with the Vitrea software v.6.9.1. The images were viewed using Multiplanar Reconstruction and Volume Rendering technique (MPR-VRT). STAT, FML, andFMB were measured and analyzed

Results: The study population comprised 57 males and 43 females with a mean age of 38.3 years, respectively. Regression analysis was used in stature estimation from FML and FMB. The standard error of estimate (SEE) of the FML was 6.18 and FMB was 6.64 for the combined population while SEE ranged from 4.77 to 5.21 cm for the male population and 6.18 to 6.30 cm for the female population respectively.

Conclusions: This study is the first to provide a metric and statistical analysis of the Foramen Magnum measurements in Northern India using PMCT and concluded that stature estimation is highly possible with minimum SEE from the Foramen Magnum measurements. Furthermore, the equations derived to estimate stature in this study can be considered as an alternative to solve forensic cases, in scenarios where only an isolated skull is retrieved and no long bones are available, which are considered better predictors to date.

Keywords: Stature estimation; Postmortem computed tomography; Foramen magnum length; Foramen magnum breath; Identification; Forensic anthropology.

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INTRODUCTION

Forensic medicine is "the application of the principles and knowledge of medical science along with circumstantial evidence, to legal investigators and proceedings in courts of law to help in the administration of justice".[1] Forensic anthropology is the application of anthropological methods and theoretical knowledge in matters of legal concern.[2] Forensic anthropology is mainly concerned with creating a biological profile of the retrieved unknown skeletal remains. This biological profile is formed from the "BIG FOUR" i.e., Stature, Race, Sex, and Age of an individual. In other words, BIG FOUR helps the legal authorities in the circumstantial identification of an unknown individual. Identification is defined as "the determination of the individuality of a person".[3] Absolute identification is highly dependent on DNA profiling and Fingerprinting while Partial identification is the "ascertainment of only some features like stature, race, sex, age.[4]

The previous studies had concluded that long bones are the better predictor of stature[5-7], however, newer studies are being conducted to prove the efficiency of other smaller bones of the body.[8-14] The probability of retrieving the intact long bone when compared to other parts, particularly in scenarios involving mass disasters, burns, or mutilated skeletal remains is less common demanding the researchers to conduct newer studies on the smaller bones which helps in better prediction of stature and thus increasingthe chances of identification of the unknown individuals. In comparing the methodologies used to conduct the study, earlier researchers performed the traditional methods of using measuring tapes and vernier caliper to measure the bones either in a percutaneous manner in the case of living subjects or by measuring from the bony landmarks after dissection in case of deceased subjects. However, the application of evolving Postmortem Multidetector Computed Tomography (PMCT) has helped researchers to a great extent that any part of the body can be studiedin both living and dead subjects without mutilation in the case of dead subjects and maintaining the dignity of the dead.

The foramen magnum is the most vital structure, observed to have various shapes situated in the occipital bone of the skull base surrounded by many soft tissues. It helps in holding the face and ensures communication between the brain and other parts of the body.[15,16] The shape and size of the Foramen Magnum (FM) are one of the criteria in clinical assessment for various surgeries related to several pathological conditions. Even though the skull has various other orifices and foramen, FM has a significant role both for clinicians for treatment, and diagnosis purposes, as well as for the forensic anthropologist for identification purposes.[17] The literature available to estimate stature from FM is very less, however, very few authors had studied the sex determination from FM based on morphometry. Hence, the author's main objective was to provide a metric and statistical analysis of the FM measurements in Northern India using PMCT which is the latest advancement in Indian Forensic Medicine.

METHODS

1. Sample collection

This cross-sectional study was conducted under the project of the Center for Advanced Research and Excellence in Virtual Autopsy at the Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences (AIIMS), New Delhi. This is a collaboration established by the two-premier institutes of the country i.e. Indian Council of Medical Research, New Delhi, and AIIMS, New Delhi. The PMCT functioning commenced on the 10th of August 2021 and by the end of the year, almost 597 PMCT examinations were completed. The data utilized in the present study were obtained from the deceased who underwent routine PMCT examination before conducting of autopsy examination. There was a variety of cases like road traffic accidents, falls from height, gunshots, electrocution, railway accidents, poisoning, hanging, strangulation, sudden death cases, etc. Northern India has the following states: Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, and Uttarakhand.Almost all the bones altering the stature fuses by 21 years, the deceased who were more than and equal to 21 years of age were included in the study. The study participants who had sustained a fracture of any bones of the body modifying the stature, had any deformity of spine altering the stature, with notable gross congenital cranial defects or skull fracture altering the measurements of the foramen magnum were excluded from the study. A total of 100 study participants were recruited for the study who were born and brought up in different states of Northern India abiding by the inclusion and exclusion criteria. A temporary identification consisting of details like serial number, postmortem no, age, sex, and locality was created in a data collection proforma before collecting the data.

2. Anthropometric measurements

PMCT examination was performed using a 16-slice MSCT spiral scanner, Cannon America Medical Systems, Inc Aquilion Lightning TSX-035A CT. Scanning parameters were 120kV and 70 mAs. 16 x 1 mm collimation was used for all the cases for data acquisition. All the raw data was processed into slices of 1mm thickness. The results of the study were evaluated with the Vitrea software v.6.9.1. The images were viewed using Multiplanar Reconstruction and Volume Rendering technique (MPR-VRT). Three variables were measured from the reconstructed imagesas shown in Fig. 1(a): Stature (STAT), Fig. 1(b) Foramen Magnum Length (FML), and Foramen Magnum Breadth (FMB). All the variables were measured using the electronic cursor (distance tool) available in the software and data were entered directly into a data collection proforma initially followed which was updated in Microsoft Excel 2016 Spreadsheet.

STAT

The starting point on the head end was from the most distal part of the vertex and the ending part in the lower limb was the distal-most part of the calcaneum.

FML

It is measured as the distance between opisthion and endobasion.

FMB

It is measured as the maximum width of the foramen magnum. Measured perpendicular to FML (Fig. 1).

3. Statistical Analysis

All these measurements were assessed twice by the investigator to ensure the intra-rater reliability of the measurement. Inter-rater reliability was assessed by measuring the parameter of randomly selected 20 cases by an independent person. All lengths were measured in centimeters to the nearest 0.1mm. The obtained data were tabulated and analyzed with the Kruskal-Wallis H test. The data on STAT, FML & FMB obtained from PMCT images was expressed as mean with SD and range. The linear relationship between the STAT and FML, STAT and FMB had been explored by using correlation analysis. Regression analysis both linear and multiple was used to establish the relationship between STAT and FML, STAT and FMB. All statistical analyses were carried out at a 5% level of significance using IBM Statistical Package for Social Sciences (SPSS)(v.23.0).

RESULTS

1. Intra-observer error and Inter-observer

The intra-observer reliability (consistency) was assessed by using the test-retest method by measuring the length 2 times by the observer and the mean values were considered for analysis. Inter-observer reliability was carried out by measuring the length by two independent observers. The reliability was explored by using Cohen's kappa. It was observed that both intra and inter-observer reliability on the measurements were found to be 98% for STAT, 97% for FML, and 98% for FMB.

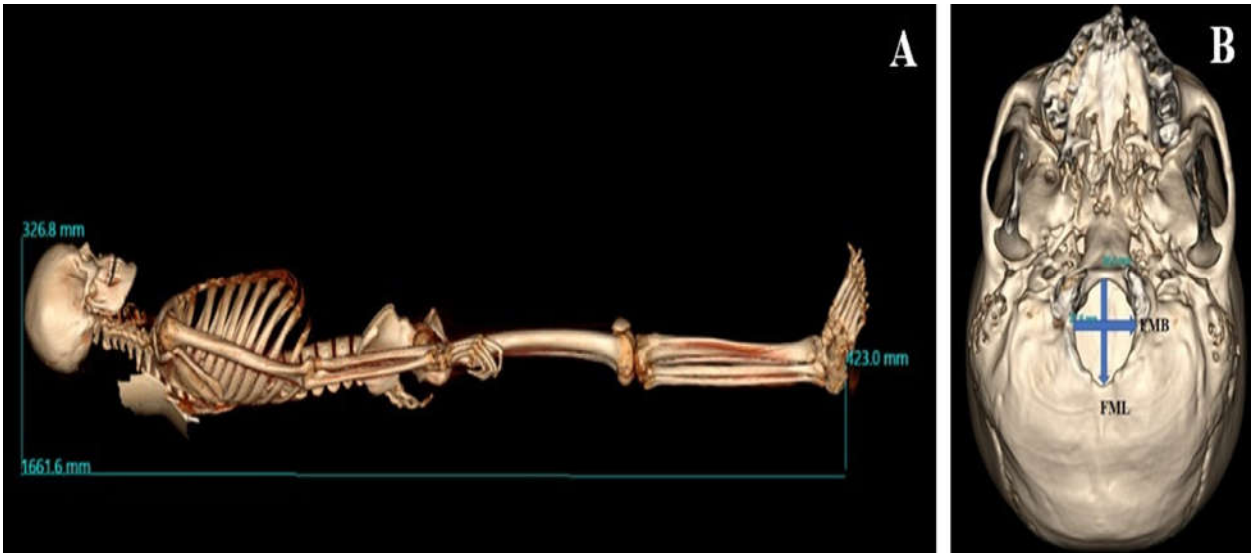

Fig. 1(a): Stature estimation using PMCT, **Fig. 1(b):** Measurements: FML & FMB

2. Sexual Dimorphism

The Kolmogorov-Smirnov test and Shapiro-Wilk test were conducted on FML and FMB to check for the normality of the population. The results reported that both were not normally distributed. Hence, the Kruskal-Wallis H test and Mann-Whitney test were performed. It was concluded that there was a significant difference in FML and FMB between male and female populations ($p<0.05$).

3. Descriptive statistics

100 subjects participated in this study, among which 57 (57%) were males and 43 (43%) were females. The randomly collected 100 population subjects, were further segregated according to age and gender. The descriptive statistics for the entire population, males and females are presented in Table 1. The independent variable age was mentioned in years, all the other outcome variables were measured in cm. The mean FML (anteroposterior diameter) of the study population was higher than the mean FMB (transverse diameter). Similarly, the mean anteroposterior diameter was greater than the mean transverse diameter in both the male and female populations. The male population had a higher mean FML and mean FMB than the female population. However, the maximum transverse diameter was the same in both male and female populations while the females showed a lesser value of minimum FML, maximum FML, and minimum FMB.

Table 1: Descriptive Statistics [* age in years, all measurements are in cms]

Sex/ Parameters	Combined		Male		Female	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Age	37.3(14.94)	21-77	37.14(13.88)	21-70	39.97(16.28)	21-77
STAT	159.25(8.85)	138.5-179.4	163.9.25(6.49)	150.3-179.1	153.1(7.74)	138.5-179.4
FML	3.71(0.65)	2.21-5.97	3.95(0.65)	2.21-5.97	3.40(0.52)	2.24-4.92
FMB	3.17(0.60)	1.86-4.97	3.36(0.58)	2.49-4.97	2.91(0.53)	1.86-4.97

STAT - Stature, FML - Foramen Magnum Length, FMB - Foramen Magnum Breath, SD - Standard Deviation

4. Correlation analysis

The correlation coefficient determines the strength and the direction of a linear relationship between two variables. Pearson correlation was used to determine the association between FML and STAT. There was a significantly higher correlation ($p<0.01$) observed between STAT and FML, STAT and FMB for both combined and gender-wise populations. There was a significant positive correlation with a higher correlation coefficient for the anteroposterior diameter than the transverse diameter. After clustering the sample population based on gender, a significant positive correlation was observed between STAT and FML measurements ($p<0.05$). Pearson correlation coefficients of the male population were greater than the female population. Similarly, the Pearson correlation between STAT and FMB showed a significant positive correlation ($p<0.05$). The male population had a better correlation than the female population. (Table 2).

Table 2: Pearson Correlation Coefficient and Linear Regression Equations (LRE) for estimation of stature (cm)

Sex	LRE	SEE	R^2	R	P
Combined (n=100)	S = 123.15 + 9.71* (FML)	6.18	0.52	0.72	P<0.001
	S = 128.32 + 9.77* (FMB)	6.64	0.44	0.67	P<0.001
Males (n=57)	S = 136.92 + 6.82* (FML)	4.77	0.47	0.69	P<0.001
	S = 141.34 + 6.71* (FMB)	5.21	0.37	0.61	P<0.001
Females (n=43)	S = 121.62 + 9.25* (FML)	6.18	0.38	0.62	P<0.001
	S = 127.73 + 8.71* (FMB)	6.30	0.36	0.60	P<0.001

5. Multiple regression analysis

The accuracy of estimating the stature can be increased by the application of numerous regression equations.[18] Thus, the authors formulated multiple regression equations to examine the human height estimation accuracy presented in Table 3. This study achieved a higher stature estimation accuracy in multiple regression equations in all cases due to higher values of R (R: 0.75 for the combined dataset, R: 0.71 for males, and R: 0.67 for females). In addition, lower SEE values (± 5.93 cm for the combined data set, ± 4.66 cm for males, and ± 5.92 cm for females).

Table 3: Multiple Regression Equations (MRE) for estimation of stature(cm)

Sex	R	R^2	SEE	MRE	P
Combined (n=100)	0.75	0.56	5.93	120.07 + 6.74(FML) +4.46 (FMB)	P<0.001
Male (n=57)	0.71	0.50	4.66	134.32 + 5.09 (FML)+2.82 (FMB)	P<0.001
Female (n=43)	0.67	0.44	5.92	118.54 + 5.92(FML) + 4.93 (FMB)	P<0.001

DISCUSSION

The sole purpose of performing metric analysis of the bones of the human body is to find the stature of an individual from an unknown bone. This would be helpful in scenarios where a skeletonized body is received for identification purposes. However, the stature estimation will be a million-dollar question particularly if the sex of the bone is not known. Hence, the researchers suggested that stature estimation should succeed the sex determination.[19] The stature is estimated purely based on regression equations derived from the metric analysis of the various bones. The present study confirms that the foramen magnum can be utilized for the estimation of the stature of an abandoned skull from the North Indian population. The stature can be correlated even though gender is unknown, with the help of the regression equation specific to the population with a minimal SEE (6.18 for FML and 6.64 for FMB) and higher coefficient of determination (0.52 for FML and 0.44 for FMB). Yaming Cui et al in their study on metric analysis of the foramen magnum region on the Chinese population observed a SEE of 7.03(FMB) for the regression equation specific to their population. They observed a correlation coefficient of 0.31(FMB), p<0.01 and 0.71(FML), p>0.01 while the authors of this study observed 0.67(FMB), p<0.01 and 0.72(FML), p<0.01. The wide variation in the results could be due to the variation in the procedures undertaken in the study. The present study performed the measurements with the help of the PMCT software without any treatment of the bones and the electric cursor was used to measure the most exact dimensions. However, the authors of the Chinese study used vernier calipers to measure the measurements of the foramen magnum. The other difference could be the reduced sample size in the present study as the authors of the Chinese study analyzed 276 subjects.[14]

The comparative analysis of the correlation coefficient and SEE of the present study with a few other studies showed that the current study had a higher correlation, better coefficient of determination and lesser SEE in both gender with a P value <0.001 [Table 4].

Table 4: Comparison of the present study with other studies – Males & Females

Author, Place (year)	Variables (Sample size)	Correlation Coefficient	P Value	SEE	R^2
		Males			
Babu *et al.*, South India (2014)[20]	FML (51)	0.063	0.471	-	-
	FMB (51)	0.344	0.001	-	-
Villarreal M, American White (2015)[21]	FML (117)	0.18 (0.05)	0.059	-	-
	FMB(117)	0.30	0.001	5.82	-
Zhan M J *et al.*, Chinese (2019)[14]	FML (200)	0.15	0.035	6.28	-
	FMB (200)	0.34	<0.001	5.97	-

Table Cont...

Gilbe P S et al., Western India (2020)[23]	FML (81)	0.69	-	5.6	0.48
	FMB (81)	0.75	-	5.1	0.56
Present Study (2021)	FML (57)	0.69	<0.001	4.77	0.47
	FMB (57)	0.61	<0.001	5.21	0.37
Females					
Villarreal M, American White (2015)[21]	FML(115)	0.14	0.14	-	-
	FMB(115)	0.15	0.11	-	-
Zhan *et al.*, Chinese (2019)[14]	FML (200)	0.12	0.120	5.79	-
	FMB (200)	0.26	0.261	5.63	-
Gilbe P S *et al.*, Western India (2020)[23]	FML (55)	0.45	-	6.9	0.20
	FMB (55)	0.68	-	5.6	0.47
Present Study (2021)	FML (43)	0.62	<0.001	6.18	0.38
Present study (2021)	FMB (43)	0.60	<0.001	6.30	0.36

However, these differences in results observed among the studies listed could be due to differences in region, race, occupation, socioeconomic and nutritional factors as stated by the previous researchers[20-26] in addition to differences in sample size between the present study and other studies compared. The correlation coefficient of FMB with STAT was better among Nagpur males and females when compared with the North Indian males and females of the present study.[23] The comparison of the morphological pattern of FM observed in the current study when compared with other studies[27,28] confirmed the presence of variation in the anteroposterior diameter and the transverse diameter. The morphological results of the present study showed that the anteroposterior diameter is more than the transverse diameter (Table 5).

Table 5: Comparison of FML and FMB various studies with present study-Population Specific, Male Population and Female Population.

Study (year)	FML			FMB		
	Min	Mean	Max	Min	Mean	Max
Population Specific						
Cui Y *et al.*, Chinese (2013)[22]	2.32	3.57	4.51	2.51	3.03	4.03
Cui Y *et al.*, South Chinese (2013)[22]	2.32	3.56	4.51	2.62	3.04	3.68
Cui *et al.*, North Chinese (2013)[22]	3.08	3.57	4.22	2.57	3.06	4.03
Moodley M *et al.*, South Africa (2019)[27]	2.63	3.52	4.15	2.36	2.87	3.71
Kumar A *et al.*, Northern India (2018)[28]	3.22	3.41	3.62	2.58	2.82	3.08
Present study (2021)	2.21	3.71	5.97	1.86	3.16	4.97
Male Population						
Kanchan T *et al.*, Mangalore (2013)[29]	2.70	3.45	4.10	2.30	2.73	3.2
Babu *et al.*, South India (2014)[20]	3.3	3.89	4.9	2.9	3.32	4.6
Villarreal M, American White (2015)[21]	2.87	3.77	4.58	2.76	3.21	3.92

Table Cont...

Zhan *et al.*, Chinese (2019)[14]	2.83	3.45	4.23	2.40	2.93	3.49
Moodley M *et al.*, South Africa (2019)[27]	2.84	3.57	4.16	2.47	2.94	3.51
Gilbe P S *et al.*, Western India (2020)[23]	1.9	3.1	3.8	2.3	2.9	3.5
Present study (2021)	2.21	3.95	5.97	2.49	3.36	4.97
Female Population						
Kanchan T *et al.*, Mangalore (2013)[29]	2.70	3.36	3.90	2.2	2.67	3.1
Villarreal M, American White (2015)[21]	2.57	3.65	4.58	2.39	3.13	3.92
Zhan *et al.*, Chinese (2019)[14]	2.89	3.35	4.07	2.39	2.89	3.51
Moodley M *et al.*, South Africa (2019)[27]	2.67	3.43	3.87	2.38	2.79	3.71
Gilbe P S *et al.*, Western India (2020)[23]	1.5	2.7	3.3	2.1	2.6	3.1
Present study (2021)	2.24	3.40	4.92	1.86	2.91	4.97

However, several researchers had studied various shapes of the foramen magnum and estimated sex[29], which the authors of the present study would explore in the future. An age-wise analysis concluded that the anteroposterior diameter continued to be greater than the transverse diameter as aging happened. However, the mean FML and mean FMB in the second decade were lesser when compared to the mean FML and mean FMB in the third decade. The mean values of both the FML and FMB dropped down from the fourth decade onwards (Table 6). This finding was contradictory to the observations of Hoyte[30] and Scheuer and Black[31] that bone resorption in the older stages of life causes an increase in the dimension of the foramen magnum region as the present study reports a decrease in the diameter as the aging happens. However further studies on the Indian population should validate our findings for a better understanding.

Table 6: Comparison of FML and FMB age-wise; Males and females separately

		FML				FMB			
Years	**N**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
21-30	41	2.67	5.49	3.73	0.60	2.39	4.97	3.24	0.65
31-40	22	2.82	5.97	3.89	0.79	1.94	4.87	3.61	0.72
41-50	15	2.21	4.47	3.46	0.59	2.39	4.05	3.28	0.39
51-60	12	2.86	4.35	3.38	0.68	1.86	3.78	3.15	0.59
>60	10	2.79	4.14	3.15	0.40	2.68	3.71	3.04	0.34

The derived regression equation was validated by applying it to 10 randomly selected males and females respectively from the study population. The calculated stature observed on the application of the FML equation showed less difference in values than the FMB equation. The magnitude of the difference between observed and calculated stature is less than 2cm when FML equations were applied and less than 4cm when FMB equations were used. On applying the FML equation, 40% of males showed a difference of less than 0.5cm, 20% showed a difference in the range of 0.5-1cm, and 40% showed a difference of 1-1.5cm. The female population using the FML equation showed a similar result however 10% of the females showed a difference of 2.2cm. On the other hand, when the FMB equation was used, 80% of both males and females showed a difference of less than 3cm and 20% of both males and females respectively portrayed a difference in the range of 3cm to 4cm. Hence, the inference from the validation of the equations suggested that four proposed equations

for estimating stature based on the FML and FMB are of practical value when the gender of the skull was known.

CONCLUSION

Linear regression equations for stature estimation from FML and FMB were established in this study. The correlation coefficients between STAT and FML, and STAT and FMB were highly significant and strongly correlated. The authors conclude that foramen magnum measurements in the North Indian population can be considered a reliable predictor of stature. Thus, in scenarios where an isolated skull is retrieved, the linear regression equations can still assist in measuring the possible stature.

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