Determination of Sex by Osteometry of Third Metatarsal

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Abstract

In forensic anthropology and bio archaeology, sex determination is considered to be a primary step, as accurate identification of one sex eliminates half of the population of other sex. Though pelvis, cranium and long bones are considered more accurate indicators for sex determination, they are often not available or fragmented. The aim of this study is to specify the relation between prediction of sex of an individual and osteometry (length and mid shaft diameter) of third metatarsal and to assess the reliability of these morphometric traits in predicting the sex of the individual. Sample used in the study were 100 cases (50 males and 50 females) presenting for post mortem examination in the mortuary of Lok Nayak Hospital and Maulana Azad Medical College. The present study found sex determination accuracy of third metatarsal to be 67% to 72%, which rose to 75 % on combination of variables from both sides. The results suggest that metatarsal bones can be used for sex determination when remains are fragmented or incomplete.

Key words: *Metatarsal, Sex determination, Morphometric traits.*

Introduction

Forensic anthropology in 1979 was defined by Stewart as "the branch of physical anthropology, which for forensic purposes, deals with the identification of more-or-less skeletonized remains known to be, or suspected of being human".[1] Modern anthropology is not restricted to skeletonized remains but includes identification of alive humans too. An anthropologist faces challenges with respect to identification of race, age, sex and stature in cases where the complete remains are not available.

Sex determination is the first and important step before age, ancestry and stature estimations as sex of the individual influences all these attributes.[1] Examination methods include visual assessment (i.e. identification of special characters on skeleton) and metric analyses (i.e. measurement of bone trait). Metric based analysis is superior being examiner independent and relies largely upon statistical analysis. The most accurate sex indicators are pelvis and cranium followed by long bones.[2] But when these bones are not available, fragmented or have been rendered unexaminable, then the small bones like metatarsals come to play a significant role.

The shafts of long bones often survive exhumation but the epiphysis bear a thin layer of compact bone on fragile cancellous bone, which is prone to damage. The smaller long bones of the hands and feet often remain intact/complete.[3] Metatarsals being resistant to post-mortem changes and external trauma, are usually intact in comparison to long bones in mass disasters particularly explosions, aircraft and railway accidents. Shoe/boot protects the foot to some extent preserving the bones even in severely mutilated bodies. Though size variation due to activity or stress related robusticity is documented for the upper limbs, but this cannot be considered a factor to the same extent for metatarsals.[4]

To the best of our knowledge, metatarsals remain unstudied in Asian population and studies on sex determination using cadaver metatarsals was not found even after extensive search.

The aims of this study were:

1. To specify the relation between prediction of sex of an individual and osteometry (length and mid shaft diameter) of third metatarsal.

2. To assess the reliability of these morphometric traits in predicting the sex of the individual.

MATERIALS AND METHODS

The study was conducted on autopsy cases

coming for medico-legal postmortem examination to the Department of Forensic medicine, Maulana Azad Medical College and Associated Hospitals, New Delhi. We studied a sample of 100 cases (50 males; 50 females) above 18 years of age as the data for the purpose of sample calculation was deficient.

Metatarsals with fractures, disease, deformity, surgical repairs were excluded from the study. Also cases with conditions affecting the stature were excluded.

Method

After explaining the study to the next of kin of deceased and consent was taken to participate in study, the case was included in the study. Autopsy was performed using standard autopsy techniques. Rigor mortis, if present, was released and the length was taken. The cadaver length (vertex of head to the base of heel) was measured with a measuring tape (in centimetres). After making an incision on right and left foot in midline over the dorsal aspect, soft tissue attachments were released and third metatarsal was dissected out. The metatarsal was prepared by placing it in boiling water, cleaned and washed for taking measurements. The following measurements from metatarsal were taken:

- The length of both (left and right) third metatarsal bone was taken from the highest point to the lowest point.
- The mid-shaft diameter (cranio-caudal) was measured from the middle of metatarsal taking the thickness of cortex into consideration.

Each linear measurement was taken three times, in anatomical position using vernier calipers (in centimetres to the nearest millimetre) and their average was recorded. The metatarsal after its measurement was put back in its place in the body before handing over the body to the relatives of deceased.

The data obtained was entered in excel spreadsheet and appropriate statistical analysis were done using SPSS 20 software.

Observations and Results

Of the 100 individuals used in this study, 50 are male (50%) and 50 are female (50%). The data belonged to north Indian Population.

The Kolmogorov-Smirnov and Shapiro-Wilk test revealed that the data was normally distributed. The Wilcoxon signed ranks test for bilateral asymmetry found no statistically significant difference between the right and left metatarsals.

Determination of Sex

Table 1 shows the descriptive statistics of measured values of metatarsal grouped by sex and side. All measurements were higher in males.

Sex		N	Mean	Std. Deviation	Minimum	Maximum	Std. Error of Mean	Range
F	RML	50	6.6980	0.5053	5.80	7.60	0.0715	1.8
	RMS	50	0.8260	0.0487	0.70	0.90	0.0069	0.2
	LML	50	6.7020	0.5077	5.80	7.60	0.0718	1.8
	LMS	50	0.8220	0.0464	0.70	0.90	0.0066	0.2
M	RML	50	7.1140	0.4091	6.20	8.00	0.0579	1.8
	RMS	50	0.9040	0.0832	0.80	1.10	0.0118	0.3
	LML	50	7.1120	0.4211	6.20	7.90	0.0596	1.7
	LMS	50	0.9040	0.0880	0.80	1.10	0.0124	0.3
Total	RML	100	6.906	0.5029	5.8	8.00	0.0503	2.2
	RMS	100	0.8650	0.0783	0.70	1.10	0.0078	0.4
	LML	100	6.9070	0.5077	5.80	7.90	0.0508	2.1
	LMS	100	0.8630	0.0812	0.70	1.10	0.0081	0.4

Demarking point analysis finds a point at which the one sex is excluded. In the study population, the demarking point for metatarsal length was 7.6 cm for females and 6.2 cm for males. That is, metatarsal length > 7.6 cm definitively excludes the female sex and indicates a male and metatarsal length being < 6.2 cm definitively excluded the male sex and indicates a female. The demarking point for mid-shaft diameter was 0.8 cm for females and 0.9 cm for males. Meaning that metatarsal with mid-shaft diameter of < 0.8 cm cannot be a male and hence will be female and > 0.9 cm cannot be a female and hence will be male.

Wilcoxon signed rank test and Wilk's Lambda test showed that there was a statistically significant difference between the values obtained from male and female populations. Spearman's rho correlation for the total population showed significant correlation with all metric parameters for sex determination with p-value being < 0.001. Mid-shaft diameter (Right- 0.497, Left -0.500) showed better correlation than the metatarsal length (Right- 0.398, Left -0.376). Sexual Dimorphism Index [SDI = (Xm - Xf/Xm)*100] where X represents the sample mean for each measurement.[5] The mid-shaft diameter (pooled SDI 17.30) has better SDI as compared to metatarsal length (pooled SDI 11.62) as shown in table 2.

Table 2: Sexual Dimorphism Index

Side	ML	MSD
R	5.85	8.23
L	5.77	9.07
Pooled	11.62	17.30

Receiver operator curve showed that area under the curve was higher for mid-shaft diameter than for metatarsal length indicating higher accuracy of mid-shaft diameter in predicting the sex of the individual. The co-ordinate of the curve showed that when metatarsal length is ≤ 6.05 cm the sensitivity will be 98 % and specificity will be 100% in assuming the sex to be female. Whereas, if metatarsal length is ≥ 7.7 cm, sensitivity will be 84 % and specificity will be 100% in assuming the male sex. For mid-shaft diameter, the co-ordinate of the curve showed that when the diameter is ≤ 0.75 cm the sensitivity will be 98 % and specificity will be 100% in for female sex. At the upper end when mid-shaft diameter is ≥0.95 cm, sensitivity will be 28% and specificity will be 100% in assuming the male sex.

Predicted percentage for sex determination using univariate logistic linear regression showed that mid-shaft diameter is better predictor than metatarsal length. Multivariate logistic analysis considering all the variables of both sides increased the prediction to 74%. With females (76%) having a higher sex prediction than males (72%).

However, the rise in the prediction using multivariate regression was not significant ($p > 0.05$). Thereby indicating that the measurements taken from the metatarsal are individually significant in identifying the sex of an individual; though the prediction accuracy increased by combining these parameters, it was not a significant rise.

Discussion

Side symmetry:

The metatarsal measurements of right and left side did not show any significant difference indicating the uniform distribution of physical stress between the lower limbs unlike in upper limbs where the difference is expected. Researchers suggest that the dimorphism in foot bones are most likely due to the difference in body size between males and females indicating that the intrinsic factors of sexual dimorphism by gonadal and pituitary hormones plays a major role.[6]

Measurements from metatarsal:

On comparing metatarsals measurements reported by different researchers, mean values obtained in this study are consistent with the reports of Mountrakis[5] but mean metatarsal length was higher and mean shaft diameter was lower than values reported by Abdel.[7] The population studied by C. Mountrakis and Adbel are expected to have a taller stature and bigger metatarsals than the Indian population. As the present study examines freshly dissected metatarsals where intact articulation capsule the measurement are likely to be higher. Also in radiological study by Adbel, the angulation of the bone appears to make a difference.

Determination of Sex

Sexual dimorphic index calculated for metatarsal length and mid shaft diameter were 11.62 % and 17.30% respectively. It confirms the sexual dimorphic property

of 3rd metatarsal morphometry. SDI obtained in our study was indeed higher than calculated by C. Mountrakis as 7.92 % and 9.08 % for metatarsal length and mid-shaft diameter respectively.[5]

The present study found sex determination accuracy of third metatarsal to be 67% to 72%, which rose to 75 % on combination of variables from both sides. This accuracy is consistent with report of Alicia K Wilbur but lower than the reports of Roblin, Smith, Abdel and C. Mountrakis.[5, 7-10] This variation in accuracy can be attributed to different ancestry of the study population, sample collection techniques and processing. For example, Abdel studied the radiological measurements of metatarsal from the highest point to the lowest point with the bones in angulated state. Although his study gave 100 % accuracy in predicting original study samples of 160, but when tested on a sample of 80, the accuracy fell to 96.25 %. Mountrakis obtained accuracy ranging 80.7% - 90.1% after measuring the maximum length of archaeological metatarsals along with other measurements as medio-lateral and dorso-plantar width of base, mid-shaft and head.[5] He noted that metatarsal length may change slightly at proximal and distal ends due to activity and remodelling related changes, but with limited effect. Case and Ross obtained correct classification rates exceeding 80% with a stepwise analysis model based on phalangeal and metatarsal measurements.[11] Kautilya observed that foot breadth correlates best with sex of the person instead of foot length that is consistent with our findings on studying the metatarsal bone.[12]

Table 3: Comparison of the corrected prediction with other studies

STUDY BY	SAMPLE SIZE	SAMPLE	CORRECT CLASSIFICATION
Robling AG and Ubelaker DH9	200	Archaeological	83 – 100%
Smith10	40	Archaeological	77 – 84 %
C. Mountrakis5	225	Archaeological	80.7% - 90.1 %
Abdel Moneim7	160	Radiology of living	100 %
Alicia K Wilbur8		Archaeological	72 %
Present Study	100	Cadaver	67 – 72 %

Comparison of sex prediction of metatarsal with other bones

Different studies give different prediction percentage for the same variable observed, as shown in table 4. This variability can be due to population ancestry, experience of the author, variation in techniques employed by them and special circumstances peculiar to study. For example, Krogman's samples were from a medical school where the ratio of male to female cadaver was 15:1.[2] Thus, Krogman with his experience while predicting the sex, in cases of dilemma had to roll the dice towards male where he had 15 to 1 chance of being correct. The prediction variability due to ancestry is appreciated by Flanders. He studied 200 sacri and reported the accuracy varying from 84% in whites to 91% in blacks in absence of bias arising out of observer and technical differences.[13] Pelvis is the best bone for sex prediction, the accuracy of correct classification as per Krogman is 95%.[2] Abdel's testing of metatarsals gave a prediction of 96.25%, which has been as high as that of the studies done on pelvis.[7] Indeed, it was higher than the prediction value obtained from skull (Krogman 92% and Stewart 80%).[1,2] Though the prediction percentage obtained in present study are significantly lower than pelvis and skull

but importance of metatarsal needs emphasis in situations where fragments of long bones or destroyed axial skeleton are available for examination. When fragments are available like the lower end of the humerus, the prediction with those fragmented bones has been equal to that of the metatarsals.[14,15]

Table 4: COMPARISON THE CORRECT CLASSIFICATION WITH OTHER BONES

BONE	STUDY	
Entire Skeleton	Krogman2 100%	Stewart1 90%-95%
Skull	Krogman2 92%	Stewart1 80%
Mandible	Hu16 93% (Males)	Hu16 74% (Females)
Ramus Flexure in Mandible	Loth17 94%	Donnelly18 63% - 69%
Pelvis (Phenice method)	Phenice19 96%	Bruzek20 80%
Sacra	Flander13 84% (Whites)	Flander13 91% (Black)
Lower end of humerus	Falys14 79.1%	Vance15 75.5%

The data suggest that metatarsals cannot substitute a primary bone for sex determination but it can be used to determine sex where skeletal remains are fragmented or incomplete, which is a frequent occurrence in medico-legal cases. The accuracy of prediction is expected to increases further when metatarsal is combined with other bones. However, further studies are needed for the testing the applicability of this model to archaeological remains, an effort that presents a range of theoretical and methodological challenges, primarily in terms of population continuity, secular and behavioural changes.

Conclusion

This study demonstrates that third metatarsal showed correlation with sex determination. Mid-shaft diameter proves to be a better pointer to the sex of individual rather than the length of metatarsal. The maximum prediction accuracy obtained for sex determination was 75 % after combination of length and mid-shaft diameter of one side which was almost equivalent to those obtained by examination of long fragmented bones. The specificity was high when the bones of extremes of measurements were encountered where mid-shaft diameter of <0.75cm has a specificity of 100% for females and a diameter of >0.95 cm is 100% specific for being a male.

We recommend that this study be carried out more extensively on larger samples in different populations (as in different regions of our own country) separately and in combination with other bones to arrive at a final conclusion regarding the validity of this method in prediction of sex and stature of the individual. The standards of the study should not be applied to archeological samples and skeletonized dried remains where shrinkage is a known phenomenon.

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