Original Research Article

# Sex determination from adult human tibia by direct discriminant function analysis

**Bhaskar B.Reddy[1] , M.A. Doshi[2]**

[1]PhD Scholar, Department of Anatomy, Krishna Institute of Medical Sciences Deemed University, Karad.

[2]Professor & Head, Department of Anatomy, Krishna Institute of Medical Sciences Deemed University, Karad.

**Corresponding author:** Bhaskar B.Reddy, PhD Scholar, Department of Anatomy, Krishna Institute of Medical Sciences Deemed University, Karad

## ABSTRACT

**Background:** Determination of biological sex is one of the most important determinations to be made from human remains and is an essential first step in the development of the biological profile in forensics, anthropology and bioarchaeology. The aim of this study was to determine whether sexing of unknown adult human Tibia bones can be done by applying values of morphometric parameters and formulae generated by present study on adult human tibia bones of known sex and to find out the best parameters for sex determination.

**Methods:** Various metric measurements were recorded using osteo metric board, measuring tape, non elastic thread, sliding calipers and vernier calipers on adult human tibia bones.

**Results:** Sex was correctly estimated by using direct discriminant function analysis for the tibia 95.6% of males and 89.5 % of females with a total accuracy of 93.5%.

**Conclusions:** Present study exhibited better classification accuracy for multiple variables than those of single variables. In the Tibia, the most discriminating variable in direct analysis is circumference of mid shaft.

**Keywords**: Sex determination, Circumference of mid shaft, Direct discriminant analysis, Tibia bone.

## INTRODUCTION

Sex determination of the human skeleton has been studied in forensic and physical anthropology.[1] Since the beginning of the field of physical anthropology, osteologists and anatomists have studied human remains in order to provide new and more accurate ways of building the biological profile.

When unidentified skeletal remains are found in natural mass disasters like earth quakes, tsunamis, landslides, floods etc., and in man-made disasters such as terrorist attacks, bomb blasts, mass murders and in cases when the body is highly decomposed or dismembered to deliberately conceal the identity of the individual, a biological profile is created by a forensic anthropologist to help estimate the sex, ancestry, age, and stature of the individual. Of all of these, sex is one of the most important aspects, as it is a key element in the process of identification.

While DNA analysis has proven successful in identifying unknown victims and perpetrators of crime, it is of little value when there are no family members to positively identify or claim the deceased. [2,3,4]

In India, forensic pathologists frequently encounter situations in which standard avenues for identification, e.g., fingerprints, DNA and ante mortem dental records, are of little or no value. In these situations, Forensic personnel frequently consult the Anatomists to give their expert opinion for medico legal purposes, regarding the personal identity with respect to sex, age, stature, race and also probable cause of death. Examination of such skeletal remains forms the basis of their opinion.[5,6]

In the present scenario, forensic anthropologists are involved in discovering new methods of identification from skeletal remains, cadavers as well as living beings. The reason to work on new populations is that the earlier acquired standards of age and sex determination have lost their values due to secular changes in the modern populations.[7,8] Therefore, there is always a need to apply and test the methods to newer populations for making population standards for achieving precision and accuracy.

Therefore, it was suggested that osteometric studies should be considered “population specific”, which implies that sexual dimorphism varies between populations to such an extent that osteometric standards developed from one group cannot be reliably used on another population.[9]

Very few studies are available in India on determination of sex from human Tibia bones, so present study made a sincere effort to enhance the accuracy of sex determination from adult human Tibia bones using various parameters by applying direct Discriminant function analysis on population of Marathwada region of Maharashtra.

**METHODS**

The bones used in this study were obtained from Govt. Medical College, Aurangabad, Maharashtra. For the study, fully ossified dry bones, free of damage or deformity were used. Total of 275 bones were selected for the study out of which 180 were of males and 95 were of females. All the measurements were measured in millimeters. Present study was done on dry human bones, so ethical issues were not arised.

1. Length (L) : distance between the most superior point of upper end (intercondylar eminence) and most inferior point of lower end (tip of medial malleolus) is measured with the help of Osteometric board.
2. Circumference of upper end (CUE) : a point is fixed at the margin of condyle and marked. By running non elastic thread from that point around the margin and condyles again back to fixed point. Thread is measured on scale.
3. Circumference of lower end (CLE) : a point is fixed at the level of plane of lower end and marked. By running non elastic thread from that point around the margin again back to fixed point. Thread is measured on scale.
4. Mid shaft circumference (CMS) : circumference is measured with non elastic thread around mid shaft of tibia and thread length is measured on scale.
5. Antero-posterior diameter of upper end (APD-UE) : maximum diameter of upper end between its anterior and posterior aspect is measured with vernier calipers.
6. Antero-posterior diameter of lower end (APD-LE) : maximum diameter of lower end between its anterior and posterior aspect is measured with vernier calipers.
7. Transverse diameter of upper end (TD-UE) : maximum transverse diameter across the condyles is measured with vernier calipers.
8. Transverse diameter of lower end (TD-LE) : maximum distance between the two projection points on the medial malleolus and lateral surface of the distal articular region is measured with vernier calipers.

**RESULTS**

An analysis of variance test (ANOVA) provided descriptive statistics including the means, standard deviations and F-ratios of all the variables in both



www.ijbamr.com P ISSN: 2250-284X , E ISSN : 2250-2858

sex groups (Table 1). The greatest differences in mean values appeared to be in Mid shaft circumference (males: 75.74 mm, females: 64.10 mm.), Circumference of upper end (males 195.73 mm, females: 170.65 mm.)

A statistically significant difference ($p < 0.001$) was found between males and females for the osteometric variables of tibia.

A direct analysis was carried out on all individual variables of Tibia separately to identify the most constructive variable in statistically discriminating between the sexes. The results of the direct analyses and discriminant function score formula for each variable appear in Tables 2, 3 and 4 as Function 1 to 8.

By direct discriminant analysis, Circumference of mid shaft is the best discriminant variable among all variables with 95 % for males and 88.4 % for females with overall accuracy of 92.7%.

**Direct discriminant analysis of Tibia (Function 9, Tables 2, 3 & 4)**

**(all variables entered together)**

A direct discriminant analysis was applied to evaluate the diagnostic ability of all variables entered together in direct discriminant analysis.

Discriminant function score formula for Function 9 analysis of Tibia is

**D = -20.229 + 0.006* L + 0.018* CUE -0.007* CLE + 0.158* CMS + 0.034* APD-UE + 0.053* APD-LE - 0.010* TD-UE +0.041* TD-LE**

The classification accuracy of the Tibia for the discriminant function formulae are presented in Table 4.

For the Tibia, Function 9 analysis showed that 172 males out of 180 cases were correctly classified with 8 individuals misclassified as females, thus resulting in 95.6 % accuracy.

85 females out of 95 cases were correctly classified with 10 individuals misclassified as males, thus resulting in 89.5 % accuracy.

Total 257 out of 275 cases were correctly classified with total accuracy of 93.5 %.

Cross validation showed that only 2 extra cases were misclassified, therefore not greatly affecting the overall percentage.

**Table 1: Means, Standard deviations, Univariate F-ratio and demarking points for the Tibia**

| Variable Descriptions | Males (n =180 ) | | | Females (n = 95) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SE | Mean | SD | SE | F- ratio | t -test | p value |
| **TIBIA** | | | | | | | | | |
| L | 376.83 | 18.80 | 1.40 | 343.87 | 19.16 | 1.96 | 188.53 | 13.73 | .000 |
| CUE | 195.73 | 13.31 | 0.99 | 170.65 | 10.78 | 1.10 | 249.88 | 15.80 | .000 |
| CLE | 131.41 | 8.02 | 0.59 | 117.04 | 8.57 | 0.87 | 190.34 | 13.79 | .000 |
| CMS | 75.74 | 4.44 | 0.33 | 64.10 | 4.16 | 0.42 | 444.54 | 21.08 | .000 |
| APD-UE | 46.61 | 3.24 | 0.24 | 40.83 | 3.14 | 0.32 | 201.90 | 14.20 | .000 |
| APD-LE | 33.64 | 2.60 | 0.19 | 29.14 | 2.16 | 0.22 | 206.66 | 14.37 | .000 |
| TD-UE | 70.51 | 5.52 | 0.41 | 62.27 | 4.44 | 0.45 | 157.62 | 12.55 | .000 |
| TD-LE | 41.33 | 3.26 | 0.24 | 36.66 | 2.79 | 0.28 | 140.39 | 11.84 | .000 |



www.ijbamr.com P ISSN: 2250-284X , E ISSN : 2250-2858

**Table 2: Variable wise calculation of discriminant functions of Tibia (Direct analysis)**

| Function | Variable | unstandardized coefficient | standard coefficient | structured coefficient | Wilks Lambda | F ratio | eigen value | canonical correlation |
|---|---|---|---|---|---|---|---|---|
| 1 | L | 0.053 | 1 | 1 | 0.592 | 188.53 | 0.691 | 0.639 |
| 2 | CUE | 0.080 | 1 | 1 | 0.522 | 249.88 | 0.915 | 0.691 |
| 3 | CLE | 0.122 | 1 | 1 | 0.589 | 190.34 | 0.697 | 0.641 |
| 4 | CMS | 0.230 | 1 | 1 | 0.380 | 444.54 | 1.628 | 0.787 |
| 5 | APD-UE | 0.311 | 1 | 1 | 0.575 | 201.90 | 0.740 | 0.652 |
| | APD-LE | 0.405 | 1 | 1 | 0.569 | 206.66 | 0.757 | 0.656 |
| | TD-UE | 0.193 | 1 | 1 | 0.634 | 157.62 | 0.577 | 0.605 |
| 8 | TD-LE | 0.321 | 1 | 1 | 0.660 | 140.39 | 0.514 | 0.583 |
| 9 **All Variables** | L | 0.006 | 0.117 | 0.593 | 0.337 | - | 1.964 | 0.814 |
| | CUE | 0.018 | 0.226 | 0.683 | | | | |
| | CLE | -0.007 | -0.061 | 0.596 | | | | |
| | CMS | 0.158 | 0.687 | 0.911 | | | | |
| | APD-UE | 0.034 | 0.109 | 0.614 | | | | |
| | APD-LE | 0.053 | 0.132 | 0.621 | | | | |
| | TD-UE | -0.010 | -0.051 | 0.542 | | | | |
| | TD-LE | 0.041 | 0.128 | 0.512 | | | | |

**Table 3 : Discriminant function equation for determining sex of Tibia (Direct analysis)**

| Function | Variable | Constant | Discriminant equation | Group centroid | | Sectioning point |
|---|---|---|---|---|---|---|
| | | | | Male | Female | |
| 1 | L | -19.304 | B = -19.304 + 0.053*L | 0.602 | -1.140 | 0.000218 |
| 2 | CUE | -14.952 | B = -14.952 + 0.080* CUE | 0.693 | -1.312 | 0.000363 |
| 3 | CLE | -15.391 | B = -15.391+ 0.122* CLE | 0.604 | -1.145 | -0.0002 |
| 4 | CMS | -16.476 | B = -16.476+ 0.230* CMS | 0.924 | -1.750 | 0.000254 |
| 5 | APD-UE | -13.898 | B = -13.898+0.311* APDUE | 0.622 | -1.179 | -0.000163 |
| 6 | APD-LE | -13.009 | B = -13.009+0.405* APDLE | 0.630 | -1.193 | 0.000236 |
| 7 | TD-UE | -13.070 | B = -13.070+0.193* TDUE | 0.550 | -1.042 | 0.000036 |
| 8 | TD-LE | -12.765 | B = -12.765 + 0.321* TDLE | 0.519 | -0.984 | -0.000218 |
| 9 | All variables | -20.229 | B = -20.229 + 0.006* L + 0.018* CUE -0.007* CLE + 0.158* CMS + 0.034* APDUE + 0.053* APDLE -0.010* TDUE +0.041* TDLE | 1.014 | -1.922 | -0.000254 |

**Table 4 : Percentage of predicted group membership and cross validation for the Tibia (Direct analysis)**

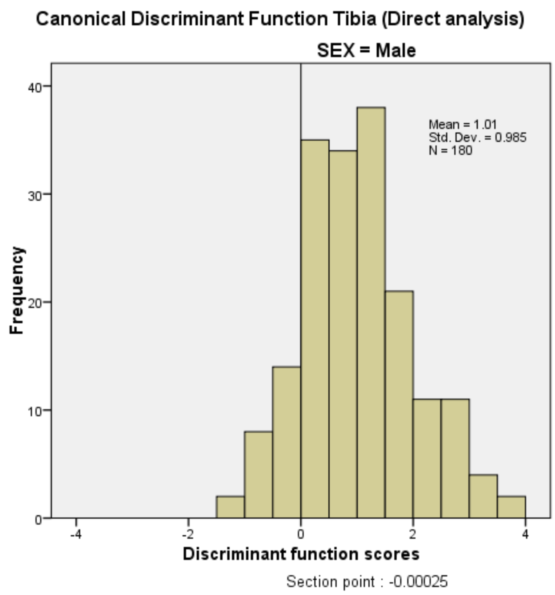
| Function | Variable | % of bones Correctly classified | | | | | |
|---|---|---|---|---|---|---|---|
| | | Male (n =180 ) | | Female (n =95 ) | | Total (n=275) | |
| | | original | Cross validated | original | Cross validated | original | Cross validated |
| 1 | L | 165 | 165 | 73 | 73 | 238 | 238 |
| | | 91.7 | 91.7 | 76.8 | 76.8 | 86.5 | 86.5 |
| 2 | CUE | 173 | 173 | 74 | 74 | 247 | 247 |
| | | 96.1 | 96.1 | 77.9 | 77.9 | 89.8 | 89.8 |
| 3 | CLE | 162 | 162 | 80 | 80 | 242 | 242 |
| | | 90 | 90 | 84.2 | 84.2 | 88 | 88 |
| 4 | CMS | 171 | 171 | 84 | 84 | 255 | 255 |
| | | 95 | 95 | 88.4 | 88.4 | 92.7 | 92.7 |
| 5 | APD-UE | 169 | 169 | 74 | 74 | 243 | 243 |
| | | 93.9 | 93.9 | 77.9 | 77.9 | 88.4 | 88.4 |
| 6 | APD-LE | 156 | 156 | 68 | 68 | 224 | 224 |
| | | 86.7 | 86.7 | 71.6 | 71.6 | 81.5 | 81.5 |
| 7 | TD-UE | 172 | 172 | 67 | 67 | 239 | 239 |
| | | 95.6 | 95.6 | 70.5 | 70.5 | 86.9 | 86.9 |
| 8 | TD-LE | 162 | 162 | 58 | 58 | 220 | 220 |
| | | 90 | 90 | 61.1 | 61.1 | 80 | 80 |
| 9 | All variables | 172 | 170 | 85 | 85 | 257 | 255 |
| | | 95.6 | 94.4 | 89.5 | 89.5 | 93.5 | 92.7 |

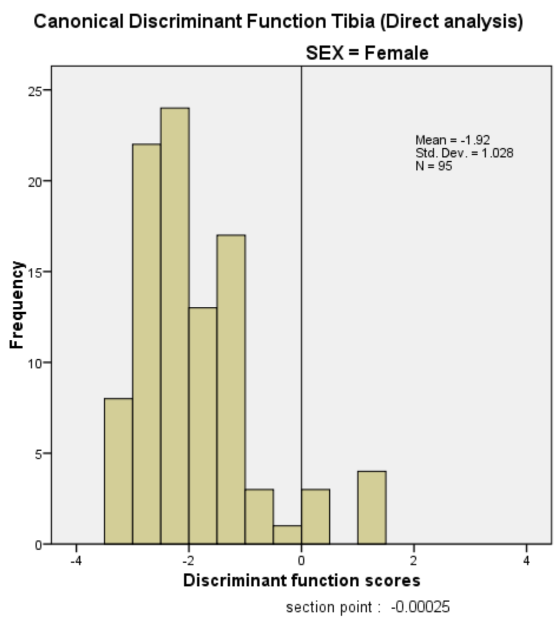
**Table 5: Comparison of Tibia metric analysis for sex determination between previous studies and our study.**

| Study | Country | Year | Method | Overall accuracy | Accuracy in males | Accuracy in females |
|---|---|---|---|---|---|---|
| Iscan et.al [12] | Whites | 1984 | CML , CNF MDNF TDNF | 87.3 | - | - |
| | blacks | | CML , CNF MDNF TDNF | 90.0 | | |
| Holland[13] | Hamann Todd collection | 1991 | CML, MPEB, MDEB | 86-95 | - | - |
| Iscan M.Y et al [15] | Japan | 1994 | CML, MPEB, MDEB APDMAS,TDMAS, APDLAS, TDLAS | - | 96 | 79 |

| | | | | | | |
|---|---|---|---|---|---|---|
| M. Steyn et al [10] | South Africa | 1997 | CML, MPEB, MDEB APDMAS, TDMAS, APDLAS TDLAS | 86 - 91 | | |
| kirici et al[16] | turkey | 1999 | CML, MPEB, MDEB | 87-89 | | |
| Gonzalez et.al[17] | Canary Islands | 2000 | CML, MPEB, MDEB | | 94.9 | 98.3 |
| Kazuhiro Sakaue[11] | Japanese | 2004 | Proximal epiphyseal Breadth | 94 | - | - |
| Rashmi Srivastava et al[18] | India | 2010 | Proximal breadth+ Distal breadth+ Minimum girth of shaft | 84.5 | 87.5 | 77.8 |
| Mario Slaus et al[14] | Croatia | 2013 | CML, MPEB, MDEB, MDNF, TDNF, CNF | 90.0 | 92.7 | 90.1 |
| Present study | India | 2013 | L, CUE, CLE, CMS APD-UE, APD-LE TD-UE, TD-LE | 93.5 | 95.6 | 89.5 |

CML = Length of the tibia
MPEB= Maximum epiphyseal breadth of the proximal tibia
MDEB= Maximum epiphyseal breadth of the distal tibia
MDNF =Maximum diameter of the tibia at the nutrient foramen
TDNF =Transverse diameter of the tibia at the nutrient foramen
CNF= Circumference of the tibia at the nutrient foramen
APDMAS= Anteroposterior diameter of medial articular surface,
TDMAS=Transverse diameter of medial articular surface,
APDLAS= Anteroposterior diameter of lateral articular surface,
TDLAS=Transverse diameter of lateral articular surface)
L =Length
CUE =Circumference of upper end
CLE =Circumference of lower end
CMS =Mid shaft circumference
APD-UE= Antero-posterior diameter of upper end
APD-LE =Antero-posterior diameter of lower end
TD-UE =Transverse diameter of upper end
TD-LE =Transverse diameter of lower end




**Graph 1. Discriminant scores of Tibia by sex using multivariate equation**

D = -20.229 + 0.006* L + 0.018* CUE -0.007* CLE + 0.158* CMS + 0.034* APD-UE + 0.053* APD-LE -0.010* TD-UE +0.041* TD-LE

**CONCLUSIONS**

Steyn and Iscan investigating a South African Caucasian population of known sex found that the distal epiphyseal breadth was the most effective for sex discrimination followed by the proximal breadth, the antero-posterior diameter, the circumference and the transverse diameter.[10] The results obtained by other workers including Sakaue,[11] using contemporary documented Japanese material, Iscan et al,[12] looking at 20th century Chinese, Japanese and Thai samples of known sex, Holland[13] documented specimens from the Hamann–Todd Collection, Slaus and Tomicic[14] investigated tibia from mediaeval Croatian sites with the sex based on pelvic and cranial morphology.

Işcan MY et al. (1994)[15] studied in population of contemporary Japan. Average prediction accuracy ranged from 80% from minimum shaft circumference to 89% with proximal epiphyseal breadth. Classification accuracy was higher in males (96%) than in females (79%).

Kirici Y and Ozan H. (1999)[16] studied in population of Turkish cadavers. Results indicated that classification accuracy ranged from 89% in the right and 87% in the left for biarticular breadth. E. Gonzalez-Reimers et al (2000)[17] studied in the pre Hispanic population of the Canary Islands. The functions obtained showed high average accuracies, ranging from 94.9 to 98.3%, with female accuracies of 100%. Rashmi Srivastava et al (2009)[18] studied in Indian population of Varanasi region, with average predictive accuracy 82.8 % (87.5 % for males and 72.2%·for females). Present study shows similar results when compared to previous research and also exhibited better classification accuracy for multiple variables than those of single variables. In summary, the measurements of the tibia appear to be high discriminators of sex in present sample analyzed by direct discriminant analysis. Circumference of mid shaft was the single most useful variable by direct discriminant function.

**ACKNOWLEDGEMENTS**

The author would like to express his gratitude to Dr. Mrs. C.V.Diwan, professor & Head, Department of Anatomy, GMC, Aurangabad for giving permission to study human skeletal remains.

Also, author would like to express his special gratitude to Dr. Mrs.Gaonkar, Controller of examinations, KIMS University, Karad, for her support and encouragement.

**DECLARATIONS**

*Funding: None*

*Conflict of interest: None*

*Ethical approval: Study involved only dry human skeletal material, so ethical approval is not required.*

**REFERENCES**

1. Krogman W.M. – "The Human Skeleton In Forensic Medicine", in “Sexing skeletal remains”, second printing. Charles C.Thomas Publisher, Springfield, Illinois. USA, (1973), 112-152.
2. Goes AC, Silva DA, Domingues CS, Sobrinho JM, Carvalho EF. Identification of a criminal by DNA typing in a rape case in Rio de Janeiro, Brazil. Sao Paulo Med J. 2002; 120(3):77-79.



www.ijbamr.com P ISSN: 2250-284X , E ISSN : 2250-2858

3. Iscan MY, Solla H.E., McCabe B.Q. Victim ofa dictatorial regime: identification of Mr. Roberto Gomensoro Josman. Forensic Sci Int. 2005; 151(2-3):213-220.
4. Oz C, Levi JA, Novoselski Y, Volkov N, Motro U. Forensic identification of a rapist using unusual evidence. J Forensic Sci. 1999; 44(4):860-862.
5. Krishan K. Anthropometry in Forensic Medicine and Forensic Science: Forensic Anthropometry; Internet J Forensic Science. 2007, Vol. 2(1).
6. Padeyappanavar KV., Kazi AM., Bhusareddy PS., Kulkarni UK. Sexual dimorphism in adult human clavicles of North interior Karnataka. J Karnataka Medico-legal Soc, 2009 June; 18(1):3-13.
7. Ulijaszek SJ, Masci-Taylor CJN. Anthropometry: The individual and the population, Cambridge studies in biological anthropology. Cambridge UK: Cambridge University Press 1994: (p213).
8. Eveleth, P B and Tanner, J M. World-wide Variation in Human Growth, Cambridge: Cambridge University Press 1976: (p287).
9. Novotny V, İşcan MY, Loth SR. Morphological and osteometric assessment of age, sex and race from the skull. In: İşcan MY, Helmer RP, editors. Forensic Analysis of the Skull. Wiley-Liss, Inc; 1993: p. 71-88.
10. M. Steyn, M.Y. Iscan, Sex determination from the femur and tibia in South African whites, Forensic Sci. Int. 90 (1997) 111–119.
11. Sakaue K. Sexual determination of long bones in recent Japanese. Anthropol Sci. 2004; 112(1):75-81.
12. M.Y. Iscan, P. Miller-Shaivitz, Determination of sex from the tibia. Am J Phys Anthropol. 1984 May;64(1):53-7.
13. Holland TD. Sex assessment using the proximal tibia. Am J Phys Anthropol. 1991 Jun;85(2):221-7.
14. Slaus M et al. Sex determination by discriminant function analysis of the tibia for contemporary Croats. Forensic Sci Int. 2013 Mar 10;226(1-3):302.e1-4.
15. M.Y. Iscan, M. Yoshino, S. Kato, Sex determination from the tibia: standards for contemporary Japan, J. Forensic Sci. 39 (1994) 785–792.
16. Kirici Y, Ozan H. Determination of sex from the tibia of adult Turkish cadavers. Kaibogaku Zasshi. 1999 Oct;74(5):537-43.
17. E.Gonzalez-Reimers et al. Sex determination by discriminant function analysis of the right tibia in the prehispanic population of the Canary Islands. Forensic Science International 108 (2000) 165–172.
18. Rashmi Srivastava et al identification of sex from tibia' by Discriminant Function' Analysis. Journal of Indian Acad Forensic Med,2009. 31(3).