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Sex Determination from Articular Ends of Tibia by Discriminant Function Analysis in Gujarati Population of Anand Region

Dr. Binita Purohit[1], Dr. Vipra Shah[2], Dr. Sapana Shah[3]

[1]Associate professor, Department of Anatomy, Dr.N D Desai Faculty of Medical Science and Research, Dharmsinh Desai University, Nadiad

[2]Associate professor, Department of Anatomy, Pramukhswami Medical College, Bhaikaka University, Karamsad

[3]Associate professor, Department of Anatomy, Dr. N D Desai Faculty of Medical Science and Research, Dharmsinh Desai University, Nadiad

Abstract:

Background: Determination of sex is the first and the most important step to identify decomposed dead bodies and skeletal remains. Next to femur, tibiaisani deal bone to study sexual dimorphism because itresistserosiveforcesandanatomicalshapeofthisboneisnotdisturbedevenafterthebodyisburied.**Aim:**This study is aimed to determine accuracy of tibia in sex determination and to derive sex discriminant function equations from the articular ends of tibia specific for Gujarati population of Anand region.**Material and methods:**Eightmeasurementsofarticularsurfacesof 97 macerated tibia (58 male, 39 female)ofboth thesides weretakenusingdigitalslidingverniercalliper with precision 0.01 mm. These measurements include maximum antero-posterior and transverse dimensions of medial and lateral articular surface of upper end of tibia; maximum distal epiphyseal breadth and length of articular surface of lower end of tibia at three levels. Data was statistically analysed, using discriminant function analysis in STATA(14.2).**Results:**All measurements in males were higher in males than in females with greater statistically significance values (p value<0.001). The maximum distal epiphyseal breadth was found to be the best parameter for the determination of sex, providing 100%accuracyin discrimination of sex from tibia. Discriminant equations specific for Gujarati population were derived from the above-mentioned measurements.**Conclusion:** This study provides useful data and standards for determination of sex from skeletal remains of tibia. Hence, it can be used for forensic investigatory cases.

Key words: Discriminant function analysis, Sexual dimorphism, Articular ends of tibia, Gujarati population, Anand region

Introduction:

Identification of individual from decomposed bodies and skeletal remains has crucial application in Forensic science. In adult skeleton, sex determination is usually the first step of identification process because the subsequent methods for age and stature estimation are sex dependent. The reliability of sex determination is dependent on availability of complete/incomplete remains of skeleton and the degree of sexual dimorphism immanent in that particular population. (Janamala RP et al., 2012). The most noticeable sex difference can be found in body size, in the majority of primates. Sexual dimorphism is very well exhibited by bones of pelvis, followed by the bones of skull. Three different types of sex determination methods are available namely morphological, metric and molecular. Out of these, the first two are anthropological because they need a detailed knowledge of osteology. The third method mentioned, acquired from the field of molecular biology, offers the most precise results for sex determination, provided that genetic material is present within the remains. This method involves DNA analysis extracted from the skeletal remains, allowing for correct identification of biological sex. (Kiskira C et al., 2022).

The accuracy of sexual dimorphism for various bones ranges from 80% to 98%, 92% for the skull and 98% for the pelvis, and only 80% for long bones (Srivastava R et al.,2009). In forensic analysis, when the skull or pelvic bones are often not available, then it becomes absolutely necessary to develop methods for the sex determination from long bones. Long bones are often found highly dimorphic especially in areas such as head and distal epiphyses of femur, proximal epiphyses of tibia (JanamalaRP et al., 2012). The tibia is often considered as an ideal bone for sex determination due to its ability to resist erosive forces and retain its shape for a longer period, even after burial and various taphonomic processes. This robustness makes it valuable in forensic anthropology and archaeology for analysing skeletal remains and determining biological sex. Its durability ensures that important morphological features used in sex determination, such as size and shape, remain relatively intact, providing reliable data for analysis. (ChatterjeePM et al.,2019). Forensic scientists typically use the skeletal features of long bones in combination with statistical methods and databases of known populations to estimate the sex of an individual with as much accuracy as possible. This information is crucial for narrowing down potential identities and helping in the investigation of cases of missing persons(ŠlausM et al.,2013).

Some researchers have explored sex determination using the proximal epiphyseal breadth of the tibia in various populations, also noting high sexual dimorphism in areas like the proximal and distal epiphyses, influenced by variable carrying angles of long bone articular surfaces.[Işcan, MY et al., (1994), González-Reimers E et al., (2000), Singh G et al.,(1975),Sakaue K.(2004)]. Iscan MY and Miller-ShaivitzP(1984) reported the tibia's superiority over the femur in showing dimorphic characteristics in American white people. Keiser JA et al.

(1992) established standards for the proximal end of tibia in South African Black people, achieving high accuracy rates in sex assessment, supporting earlier findings of Holland TD(1991) regarding the tibia's utility, especially the proximal end of tibia in sex determination.

Discriminant function analysis utilizes statistical techniques to determine the combination of measurements (variables) that can very well discriminate between males and females within same population. In forensic cases and in mass disasters, when only skeletal remains are available, this analytic method can be crucial. It allows forensic anthropologists to estimate the sex of an individual based solely on skeletal material.Different populations show variability in the osteometric dimensions and the standards which are specific for that population under study, which can be used for the sex determination. (ÖzerBK. et al.,2014)

There is dearth of research regarding sexual dimorphism of tibia (articular ends) by discriminant function analytic method in Gujarat region. Dangar KP et al. (2012) and Dangar KP et al. (2015) observed osteometric differences in proximal epiphyseal breadth and distal epiphyseal breadth in males and females by demarcating point analysis only in the year 2012 and 2015 respectively. Therefore, the present study is carried out to find out degree of sexual dimorphism with the help of various measurements of articular ends of tibia in Gujarati population of Anand region.

The present study is aimed with the following points:

1. Determine the accuracy of various measurements of articular ends of tibia in sex determination
2. Derive sex discriminant function equations for Gujarati population in Anand region.

Material and methods:

An osteometric cross-sectional study was carried out in 58 male and 39 female tibiae extracted from the donated cadavers of known sex which were used for dissection in MBBS and physiotherapy students in theDepartmentofAnatomy of Pramukhswami Medical College, Karamsad.

Inclusion criteria: The donated cadavers, used for extracting bones in the present study were of the people of Gujarati ethnicity of Anandregion as checked by the records maintained in the department. The study duration time was from July 2018 to December 2021. The permission for this study has been taken from the Institutional Ethics Committee (Reference number: IEC/ HMPCMCE/ 2018/ Ex.19).

Exclusion criteria: 1. Deformed and pathological tibia
2. Fractured of tibia
3. Tibia showing arthritic changes

Measurementsofarticular ends oftibiaofbothsides oftibiaweretaken,usingdigitalslidingverniercalliperwith accuracy of 0.01mm.Allmeasurementsweretakenby a singleauthortoavoidanyinter-observervererrorandeachmeasurementwasrepeatedtwicetoavoidanyintra-obserververror.

Definitionofthemeasurements:

A)Upperendoftibia:

Thedefinitionsofmeasurementsofarticularsurfacesofupperendoftibiahad beenadoptedfrom Janamala RP et al., (2012), but we modified parameters a little bit, so as to get more clarity on the measurements of osteometric points.

1) Antero-posteriorDimension of Medial Articular Surface of upper end of tibia (APDMAS):The maximum distancebetweenthe anteriorandposteriormarginsof medial articularsurface [AB in Plat 1].
2) TransverseDimensionofMedial Articular Surface of upper end of tibia(TDMAS):The maximum distancebetween intercondylar eminencetothemedialedgeof medial articularsurface [CD in Plat1].
3) Antero-posteriorDimensionofLateral Articular Surface of upper end of tibia (APDLAS): The maximum distancebetween the anteriorandposteriormarginsof lateral articularsurface [EF in Plat 1].
4) TransverseDimensionofLateral Articular Surface of upper end of tibia (TDLAS):Themaximum distancebetweenintercondylareminencetothelateraledgeof lateral articularsurface [GH in Plat1].

B)Lowerendoftibia:

Themethodologyformeasurementsof maximum distal epiphyseal breadth (MDEB)wereadoptedfromNanayakkara D etal.,(2019). Methodology for measurements of length of lower articular surface of lower end of tibia were adopted from Shishirkumaretal., (2014)butparametersweremodifiedin such waythatosteometricpointsfortakingmeasurements can have more clarity.

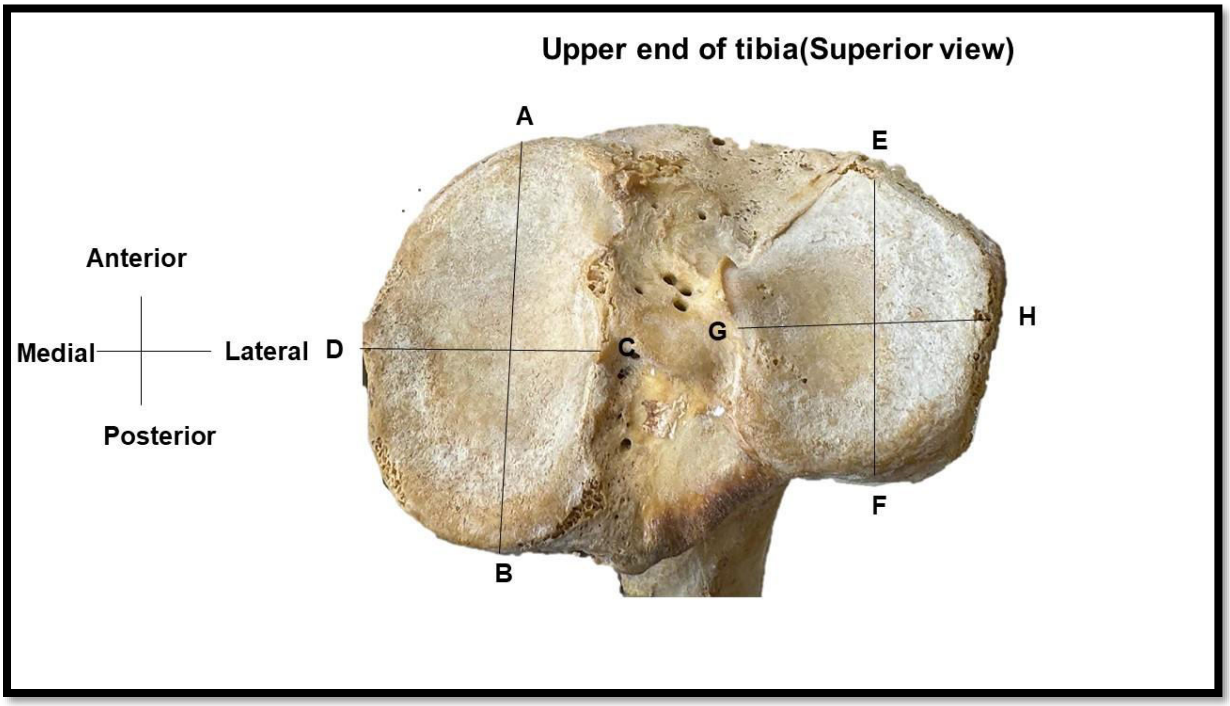
1) Maximum DistalEpiphysealBreadth (MDEB):Maximumdistancebetween the two most laterally projecting points on the medial malleolus and the lateral surface of distal epiphysis inside the fibularnotch [IJ in Plat2].

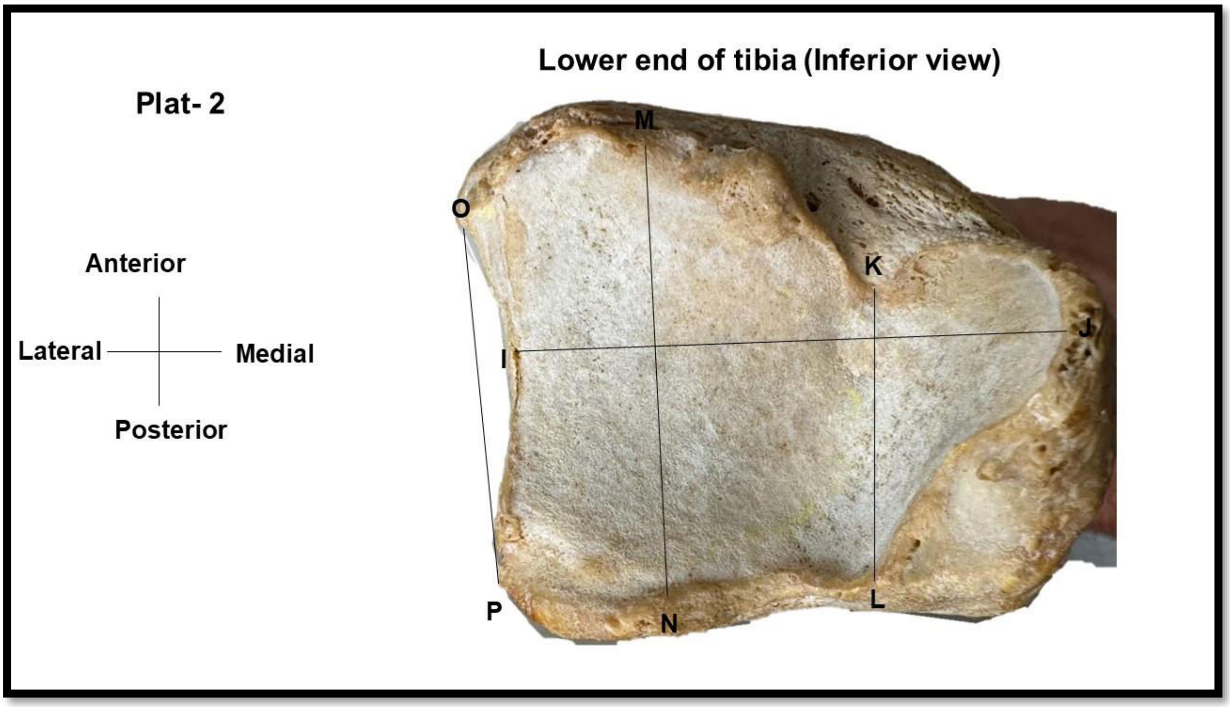
2)Lengthof lower articularsurfaceoflowerendoftibiaatthreelevels:

a.Antero-posterior Distancealongbaseofmedialmalleolusonarticularsurfaceforsuperiorsurfaceoftalus (APDBMMST) [KL in Plat 2].

b.Distance from the Centre of Anteriormarg in to the Centreof Posteriormargino farticular surface for Superior surface of Talus(DCACPST)[MN in Plat2].

c.Antero-posterior Distance alongLateralMarginofArticularSurfaceforSuperiorsurfaceofTalus (APDLMAST) [OP in Plat 2].





The data was statisticallyanalyzedbydiscriminantfunctionanalysis (both direct and stepwise method)in STATA(14.2). Descriptive statistics including mean and standard deviations were obtained for each of the dimensions separately for male and females. A one-way ANOVAtest was performed to determine the significance of differences existed between males and females. Here, the p value <0.001 was considered statistically significant.

Discriminant Function Analysis (DFA)is used to predict group membership based on observed characteristics.Discriminant function is a linear combination of the predictor traits that best discriminates between the predefined groups. DFA selects the combination of traits that most effectively distinguishes between the groups.Discriminant function equations were procured with the help of coefficient and this equation is used to calculate discriminant score.

Results:

Above-mentioned eight measurements of tibia were found to be statistically significant (p value<0.001) for determination of sex, as allthesemeasurements were larger in males than in females.

Direct discriminant function analysis:

Table 1-3 represents direct method for the discriminant function analysis. The mean and standard deviations along with F- ratios and level of significance of these eight parameters (dimensions utilized for sex determination) are depicted in table-1.

Table 2 shows standardized and unstandardized (raw) discriminant function coefficients. The unstandardized function coefficient was used to calculate discriminant function formulae. Standardized function coefficient provides information regarding the contribution of each variable in overall classification. Wilks's lambda aided to test significance of derived discriminant functions(Chatterjee PM et al.,2019).Discriminant formulae, we obtained in this method is given as below:

Discriminant score = Constant (-27.443) + variable × unstandardized coefficient.

Here, the value of sectioning point for discriminant function at group centroids —0.6825. If the discriminant score value calculated from the above formula is greater than sectioning point, then sex was classified as male, and if that score is less than sectioning point then, it was classified as female.

Table 3 shows classification accuracy of these functions. Therefore, all 58 out of 58 males and 39 out of 39 females were classified correctly with 100 % accuracy.

Table 1- Simple linear discriminant function analysis of of tibia (all variables) in a Gujarati population of Anand region for both sexes.

	Mean (SD)		F- ratio	p- value
Variable name	Male	Female		
APDMAS	48.15(3.77)	39.06(3.04)	157.30	<0.001
TDMAS	35.19(3.16)	28.45(2.41)	126.84	<0.001
APDLAS	39.68(2.37)	31.69(1.62)	335.72	<0.001
TDLAS	33.96(2.55)	27.91(2.22)	144.61	<0.001

MDEB	42.19(2.08)	32.93(1.37)	596.31	<0.001
APDLMAST	26.36(1.97)	20.58(1.48)	242.32	<0.001
APDBMMST	27.24(1.86)	21.53(1.76)	228.06	<0.001
DCACPST	31.00(2.30)	23.83(1.86)	261.55	<0.001

Table 2- Discriminant function coefficients for tibial measurements(Direct method)

Variable	Unstandardized coefficients	Standardized coefficients
APDMAS	-.004	-.015
TDMAS	.232	.488
APDLAS	-.003	-.008
TDLAS	-.101	-.245
MDEB	.370	.678
APDLMAST	.121	.218
APDBMMST	.062	.112
DCACPST	.134	.286
(Constant)	-27.443	

*Wilks' Lambda=0.85

Table 3- Percentage of classification of sex determination from tibia obtained from discriminant function analysis

		Sex	Predicted Group Membership		Total
			Male	Female	
Original	Count	Male	58	0	58
		Female	0	39	39
	%	Male	100.0	.0	100.0
		Female	.0	100.0	100.0

*100.0% of original grouped cases correctly classified.

Stepwise discriminant function analysis:

Table 4 shows three variables(measurements) of tibia entered in stepwise method, which were giving highest accuracy in sex determination (based on the values of their Wilks' Lambda).

Table 5 shows that three parameters were included in stepwise discriminant function analysis on the basis of the values Wilks' Lambda and higher F- ratios. Therefore, discriminant formulae obtained from this stepwise method is as given below:

Discriminant score= -26.841+MDEB×0.369+APDLAS×0.213+DCACPST×0.174.

The value of sectioning point by stepwise discriminant function is —0.656. Therefore, if the value of discriminant score is more than this sectioning point, sex was classified as male. If the value is less than this, sex was classified as female.

Classification accuracy by stepwise function was 100% for males, as well as for females too. Therefore, by this analytic method, sex can be classified with 100% accuracy in the selected geographical population (Gujarati population of Anand region).

Table 4-Wilks' lambda showing significance of derived discriminant functions(stepwise method)

Step	Entered	Wilks'Lambda							
		Statistic	df1	df2	df3	Exact F			
						Statistic	df1	df2	p value
1	MDEB	0.137	1	1	95.00	596.313	1	95.00	<0.001
2	APDLAS	0.104	2	1	95.00	404.108	2	94.00	<0.001
3	DCACPST	0.091	3	1	95.00	307.989	3	93.00	<0.001

*At each step, the variable that minimizes the overall Wilks' Lambda is entered.

Table 5- Discriminant function coefficients for tibial measurements(Stepwise method)		
Variable	Unstandardized coefficients	Standardized coefficients
MDEB	0.369	0.675
APDLAS	0.213	0.448
DCACPST	0.174	0.373
(Constant)	-26.841	

*Wilks' Lambda=0.91

Discussion:

Osteometric dimensions of bones are usually confined to exhibit differences between males and females. Hormones play a crucial role in bone development and maintenance. For instance, testosterone in males and estrogen in females have distinct effects on bone density, shape, and overall structure of bones. These hormones influence the rate of bone growth, remodeling, and mineralization differently in males and females, leading to variations in bone dimension. Moreover, bio-mechanical factors such as muscle mass, joint alignment, and overall body size differ between males and females. These differences affect the forces applied to bones during physical activity, which in turn can influence shape and dimensions of bones (Misiani, MK et al.,2020).

Descriptive analysis is a data analysis method to distinguish between two or more sets of objects or people based on the knowledge of some of their characteristics.(Chatterjee PM et al.,2019).Here, the comparison of best parameters (for sex determination) using various measurements of tibia by various researchers are summarized in table-6.

Table 6- Comparison of best parameters (measurements) of tibia for sex determination in different populations with present study

Author and year	Study population	Best parameter/s	Accuracy in percentage
Janamala RP et l., (2012)	Unknown sex, Tirupati (India)	Antero-posterior diameter of lateral articular surface	78%
Kiskira C et al., (2022)	Greek skeleton	maximum epiphyseal breadth of the left proximal tibia	93.4%
Srivastava R et al., (2009)	Varanasi (India)	Proximal epiphyseal breadth	82.6- 84.5%
Chatterjee PM et al., (2019)	Chhattisgarh (Central India)	Breadth of medial and lateral articular surface	93.8-95.1%
Šlaus M et al., (2013)	Modern Croatian	Proximal epiphyseal breadth	87.8%
González-Reimers E et al., (2000)	Prehispanic population from Canary Islands	Transverse diameter at nutrient foramen, proximal epiphyseal breadth, minimum shaft perimeter near distal end of tibia	94.9 to 98.3%
Sakaue K, (2004)	Japanese	Proximal epiphyseal breadth, Transverse diameter of lateral articular surface	92- 94%%
Iscan MY, and Miller-Shaivitz P, (1984)	South African blacks	Proximal epiphyseal breadth	90%
Holland, (1991)	Hamann-Todd collection	Bi-articular breadth	95%
Ozer Bk et al., (2014)	Medieval Dilkaya	midshaft circumference	73.5% to 88.7%.
Nanayakkara D et	contemporary Sri	Males- Transverse	92.9%

al.,(2019)	Lankan population	diameter of shaft at nutrient foramen	
		Females- the minimum circumference of shaft	70.4%
Misiani MK et al., (2020)	Adult Kenyan	The width of the tibial plafond	73%
Seema and Mahajan A, (2012)	Punjab (India)	Weight in males Width of upper end tibia in females	100%
Rai N et al., (2017)	Madhyapradesh (India)	Total transverse diameter (TTD) and Antero posterior diameter of Lateral condyle	79- 82%
Kranioti EF and Apostol MA, (2014)	Spanish, Italian	Upper (proximal) epiphyseal breadth	85.2–93.8 %
	Greek	Lower (distal epiphyseal breadth)	82.1 %
Novak M, (2016)	medieval Irish population	Circumference at the level of the tibial nutrient foramen	87.1 - 96%
Kranioti EF et al., (2017)	Greek-Cypriots	Upper (proximal) epiphyseal breadth	85.2%
	Cretans	Lower (distal) epiphyseal breadth	82.7%
Reddy BB et al.,(2017)	Maharashtra (India)	Mid-shaft circumference	92.7%
Present study (2025)	Gujarati population- Anand region (India)	Maximum distal epiphyseal breadth (MDEB)	100%

Various Indian researchers have reported different parameters of tibia as the best indicators for sex discrimination. Janamala RP et al.,(2012) studied human tibia ofunknown sex in Tirupati, India and found the antero-posterior diameter of lateral articular surface as the best indicator for the determination of sex with accuracy level of 78%.Srivastava R et al.,(2009) representing the Indian population in Varanasi region, observed that proximal epiphyseal breadth along with distal epiphyseal breadth and minimum girth of shaft in combination, giving accuracy of 84.5% for sex determination. Chatterjee PM et al., (2019) discovered the breadth of medial and lateral articular surface of proximal tibia as the best indicator. Rai N et al.,(2017) in their study noticed the total transverse diameter and antero-posterior diameter of lateral condyle as the best parameters for sex determination. Reddy BB et al., (2017) performed the study in the Maharashtra region and found the circumference of mid shaft tibia with accuracy level of 92.7%. Seema and Mahajan A. (2012) found that weight of tibia as best parameter for sex determination in male, and width of upper end tibia in females.However,in present study, maximum distal epiphyseal breadth was giving the best result for sex discrimination.

In current study, from proximal end of tibia, we selected four measurements of tibial condyles (maximum antero-posterior and transverse dimensions). Many researchers have shown the proximal epiphyseal breadth as the best parameter for sex determination[Kiskira, C et al., (2022), Srivastava, R et al., (2009),Šlaus, M et al., (2013), Sakaue, K. (2004), Iscan, MY &Miller-Shaivitz, P. (1984), Kranioti, EF. and Apostol, MA (2015), Kranioti, EK et al.,(2017)]. However, Kranioti EF and Apostol MA. (2015) and Kranioti EF et al., found the distal epiphyseal breadth as the best indicator for sex determination in Greek population with accuracy of 82.1% and in Cretan population (accuracy-82.7%) respectively. Kiskira C et al., (2017) reported the proximal epiphyseal breadth, followed by distal epiphyseal breadth and maximum length of tibia as the best parameters for sex determination in Greek population.

The current study shows that maximum distal epiphyseal breadth (MDEB), followed by antero-posterior dimension of lateral articular surface (APDLAS) and distancefromthecentreofanteriormargintothecentreofposteriormarginofarticularsurfaceforsuperiorsurfaceoftalus (DCACPST) were found to be the best parameter for sex determination for Gujarati population of Anand region with accuracy level of 100%. Somehow, the distal ends of the tibiae are subject to significant stress due to the weight-bearing and movement activities they endure. This stress can lead to differences in the structure and robustness of the tibiae between sexes. (Chatterjee PM et al., 2019).Holland TD.(1991), in his study observed and stated that "because the ends of the tibia are subjected to heavy stress during an individual's life, and because the stress may have a sexual component, the ends should be useful in determining sex."

When conducting this type of analysis, it is crucial to consider the geographical source of the studied skeletal remains. Additionally, one must remember that standards developed for one population cannot be applicable to other population. [Özer BK et al., (2014), Novak M. (2016)]. Consequently, the functions presented in this paper should only be applied on human remains retrieved from Gujarati population of Anand region.

Conclusion:

In our study, tibia was showing greater degree of sexual dimorphism as compared to previous studies done by various Indian authors. [Janamala, RP et al., (2012), Srivastava R et al.,(2009), Chatterjee, PM et al.,(2019), Dangar KP et al.,(2012), Dangar KP et al.,(2015), Rai N et al.,(2017), Reddy BB et al., (2017)]. The present study showed that sex can be determined from tibia with 100% accuracy in Gujarati population of Anand region. The study provides the standards that allow for accurate sex diagnosis from both complete and fragmentary tibia in the same population.Therefore, this study is crucialto develop reliable methods for sex determination using the tibia, especially in forensic contexts where skeletal remains are often incomplete.

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Legends for tables:

Table 1- Simple linear discriminant function analysis of of tibia (all variables) in a Gujarati population of Anand region for both sexes.

Table 2- Discriminant function coefficients for tibial measurements (Direct method)

Table 3- Percentage of classification of sex determination from tibia obtained from discriminant function analysis

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