The Journal of Anatomical Sciences
Email: journalofanatomicalsciences@gmail.com

J. Anat Sci 15(2)

Submitted June 30th, 2024
Accepted August 13th, 2024
Published September 30th, 2024

Sex Determination Using Tali Bones

Kareem SB, Muyideen MK, Ajiboye AA, Imam A, Ibrahim A, Alabi AS, Ajao MS

Department of Anatomy, Faculty of Basic Medical Sciences, University of Ilorin, Ilorin, Ilorin, Nigeria.

Corresponding Author: Kareem SB

Email: kareem.sb@unilorin.edu.ng; Tel: +2348033662228

ABSTRACT

The talus is an important bone used in forensic and archaeological cases for the determination of the sex of human remains because it is a preservational favored bone of the body. The study is designed to take the measurements and dimensions of dry tali to determine the sex as well as the sides of the bones. A total of 82 cadaveric bones were used. In each of the bones, measurements like tali length, breadth, widths, height, head height, head-neck length, trochlear breadth and length, length and breadth of the medial-lateral articular facet, and length and breadth of the posterior calcaneal articular surface were taken. Eleven parameters were measured on 82 bones (49 males and 33 females) obtained from the Anatomy Museum of the Anatomy Department, College of Health Sciences, University of Ilorin, Nigeria. Statistical Package for Social Sciences version 21.0 was used to analyze the discriminant function of all the measurements that were taken. The statistical analysis showed that all measured parameters were sexually dimorphic. Forty-four right tali 44 and thirty-eight left tali were found. The average accuracy for all the bones was 80.5% following the stepwise procedures from the discriminant function analysis. While the accuracy for correctly classifying the bones into males was 71% and females was 94%, the female tali bones were most often correctly classified. In conclusion, the talus bone was shown to be useful for the determination of sex.

Keywords*:* talus/tali, dimorphic, cadaveric, archaeological, skeletal remains

INTRODUCTION

The talus has been shown to be useful for human identification as it is often well preserved during excavations and easily distinguished even in a fragmentary state due to its unique morphology[1]. This increased preservation is related to the increased strength and density of the bone's trabeculae and because it is often encased in socks and/or shoes. Owing to the high incidence of recovery of intact foot bones, several studies have focused on sex determination using the talus and calcaneus[2].

Although research has shown high accuracy rates for sex determination from the talus, these studies have cited the methods to be population-specific[3]. Nearly all bones in the skeleton have been studied to calculate discriminant functions[3]. These studies indicated the utility of these foot bones for sexual assessment, with accuracy ratios from 67 to 97%[4]. Several studies indicated that sex assessment with measurements of the talus and calcaneus was highly effective among many populations. In addition, the preservation of the talus and the calcaneus tend to be good even in ancient skeletal remains representing a great potential for sex determination[4]. The percentage at which they were preserved reached 44.3– 51.1% at a Romano-British site[5]. This means that their analysis could increase the opportunity to assess the sex of skeletal remains. Although Steele, stated that the discriminant functions could be applied to remains of unknown ethnic origin[5].

In South Africa, efforts have been made to derive population-specific equations, with varying degrees of success based on average accuracy. However, the femur (68% – 91%) remains the most studied bone for sex estimation in South Africa[6]. The talus has now been shown to be a good indicator of sex, race, and categories of sex with race. Hoover, reported that length measurements (particularly those of the talus) are the most useful for distinguishing between males and females in different human populations, and provide support for the following research on sexual dimorphism in a modern skeletal population[6].

The talus is the second largest bone among the tarsals and the bone with no muscular or tendinous attachments[1]. It is the only bone through which the entire body weight load is channeled before being distributed to the arches of the foot. Sharon and Raja, reported that accurate estimations and derivations of metric features can be obtained straightforwardly from calcaneus and talus bones since these bones are compact and more durable[1]. Even, for designing and fabrication of prosthesis, data of the normal dimensions of the talus is needed. Therefore, the present study is taken up to have baseline data regarding the dimensions of the talus.

The study aims to determine the dimensions and measurements of tali bones in Ilorin, Kwara state, Nigeria which may serve as reference values for the construction of male and female footwear and the determination of sex of human remains in forensic applications.

MATERIAL AND METHODS

Randomly selected 82 dried adult tali bones of unknown sex were used. The measurements such as the length, breadth, width etc. were taken from 82 randomly selected, dry adult tali bones obtained from the Anatomy Museum at the Department of Anatomy, College of Health Sciences, University of Ilorin. Well-preserved tali bones with no obvious deformities were used. The bones were cleaned with methylated spirit and numbered using a temporary marker and masking tape. All measurements were recorded in millimeters (mm). Eleven parameters were measured from each talus following the method adopted by Steel [5] and Bidmos & Asala [7] (Figure 1): (1) tali length (TL): longitudinal measurement from the lateral tubercle to the talus head; (2) tali width (TW): longitudinal measurement from the lateral process to the talus head; (3) head-neck length (HNL): length from the tip of the head to the tip of the superior facet; (4) length of posterior calcaneal articular surface (LPAS): longitudinal length from the anterior edge of the posterior articular surface to the posterior edge of the posterior articular surface; (5) breadth of the posterior calcaneal articular surface (BPAS): longitudinal length from the medial edge of the posterior articular surface to the lateral edge of the posterior articular surface; (6) length of medial-lateral articular facet (LMAF): longitudinal length from the anterior edge of the medial-anterior facet to the posterior edge of the medial-anterior facet; (7) breadth of medial-lateral articular facet (BMAF): longitudinal length from the median edge of the medial-anterior facet to the lateral edge of the medial-anterior facet; (8) tali height (TH): longitudinal length from the lateral edge of the tali dome to the tip of the lateral process; (9) head height (HH): longitudinal length from the anterior edge of the tali head to the posterior edge of the head; (10) trochlear breadth (TRB): longitudinal length from the anterior edge of the tali dome to the posterior edge of the dome; and (11) trochlear length (TRL): longitudinal length from the median edge of the tali dome to the lateral edge of the dome (Figure 1).

The side of the body that each talus belongs to was determined by arranging the tali in rows with the trochlear up and the tali heads facing forward. If the **lateral process** of the bone appears on the left side, the talus is for the left side and if it appears on the right side, the talus is for the right side of the body (Figure 1).

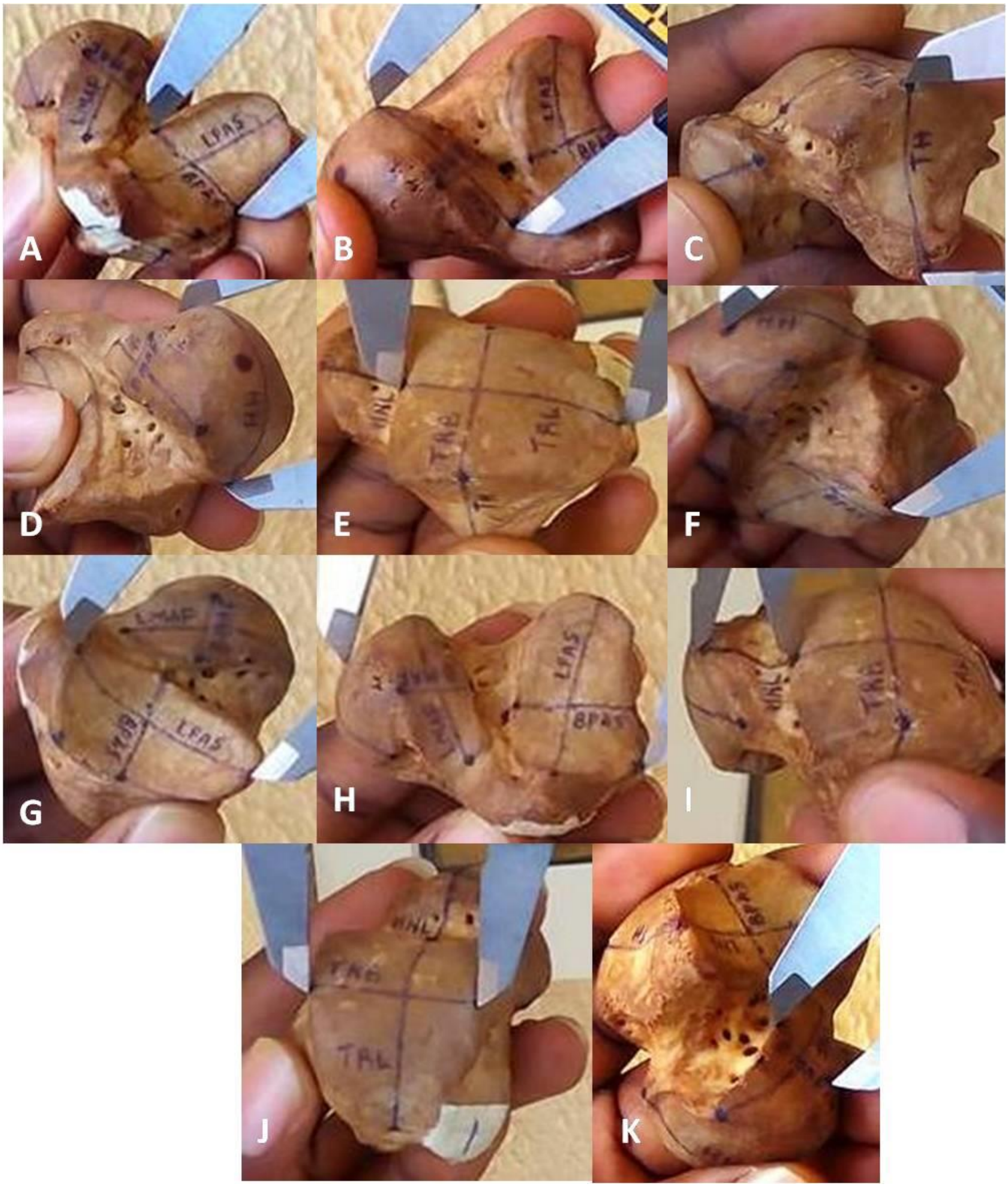

Figure 1: Showing all tali measurements, including, A- Breadth of posterior calcaneal articular surface, B- Length of Medial-Lateral articular facet, C- Tali height, D- Head height, E- Trochlear length, F-Tali width, G- Length of posterior calcaneal articular surface, H-Tali length, K- Breadth of Medial-Lateral articular facet, I-Head Neck length, and J- Trochlear breadth

Statistical Analysis

All statistical analysis was performed using the Statistical Package for Social Sciences (SPSS version 21.0) software program. Using a binomial distribution of data, the variables were first classified into different sexes from a known average value of adult male and female[8]. Then, the grouped data was subjected to a Discriminant Function Analysis which was used to get all the results and the calculated accuracies. All data were tested for normality and all variables were normally distributed. As the variables were not skewed, means and standard deviations were used as the most appropriate measures of central tendency.

RESULTS

The study measured eleven parameters on tali bones from 82 randomly selected tali to determine sex using Discriminant Function Analysis. The bones were classified into males and females using Otong and colleagues' method[8]. The talus bone's side of the body was determined by arranging the tali in rows with the Trochlear up and the Tali heads facing forward (Table 1).

Table 1a, b & c: Showing the means and standard deviation on all the parameters measured in Male and Female tali bones and the overall mean and standard deviations of both male and female tali bones combined.

Table 1a:

Parameters		Mean	Std. Deviation	Valid N (listwise)	
				Unweighted	Weighted
Male	TL (mm)	61.186531	7.0839353	49	49.000
	TW (mm)	47.497551	4.8512552	49	49.000
	HNL (mm)	17.350204	2.4541236	49	49.000
	LPAS (mm)	33.040408	3.0538425	49	49.000
	BPAS (mm)	21.507755	1.8056050	49	49.000
	LMAF (mm)	31.031020	5.1046479	49	49.000
	BMAF (mm)	14.200816	2.3446169	49	49.000
	TH (mm)	27.565102	2.3198861	49	49.000
	HH (mm)	31.755918	2.4934789	49	49.000
	TRB (mm)	28.282857	2.1036486	49	49.000
	TRL (mm)	32.289184	2.9253952	49	49.000

Table 1b:

Parameters		Mean	Std. Deviation	Valid N (listwise)	
				Unweighted	Weighted
Female	TL (mm)	53.351818	3.0937058	33	33.000
	TW (mm)	43.659091	3.8359707	33	33.000
	HNL (mm)	16.499394	2.1492062	33	33.000
	LPAS(mm)	31.912424	2.2128927	33	33.000
	BPAS (mm)	20.333939	1.5852857	33	33.000
	LMAF (mm)	29.667273	4.8050080	33	33.000
	BMAF (mm)	12.444242	1.8597026	33	33.000
	TH (mm)	26.633939	2.3209642	33	33.000
	HH (mm)	30.567576	1.9443798	33	33.000
	TRB (mm)	27.491212	2.0547168	33	33.000
	TRL (mm)	31.680909	2.5506364	33	33.000

Table 1c:

Parameters		Mean	Std. Deviation	Valid N (listwise)	
				Unweighted	Weighted
Total (combined males & females)	TL (mm)	58.033537	6.9614924	82	82.000
	TW (mm)	45.952805	4.8318348	82	82.000
	HNL (mm)	17.007805	2.3601005	82	82.000
	LPAS(mm)	32.586463	2.7876192	82	82.000
	BPAS (mm)	21.035366	1.8056176	82	82.000
	LMAF (mm)	30.482195	5.0015435	82	82.000
	BMAF (mm)	13.493902	2.3184295	82	82.000
	TH (mm)	27.190366	2.3512746	82	82.000
	HH (mm)	31.277683	2.3498454	82	82.000
	TRB (mm)	27.964268	2.1078162	82	82.000
	TRL (mm)	32.044390	2.7805786	82	82.000

KEYS:

TL-Talus length

TW-Talus width

HNL-Head-neck length

LPAS-Length of posterior articular surface

BPAS-Breadth of posterior articular surface

BMAF-Breadth of medial-anterior articular facet

TH-Talus height

HH-Head height

TRB-Trochlear breadth

TRL-Trochlear length

LMAF-Length of medial-anterior articular facet

In the ANOVA table 2, the smaller the Wilk's lambda, the more important the independent variable to the discriminant function. Wilk's lambda is statistically significant by Functions test for all the tali parameters as seen in table 2.

Table 2: ANOVA Table (table showing the Analysis of variance of all the tali parameters)

Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Significance.
TL (mm)	.692	35.666	1	80	.000
TW (mm)	.846	14.522	1	80	.000
HNL (mm)	.968	2.614	1	80	.110
LPAS(mm)	.960	3.321	1	80	.072
BPAS (mm)	.897	9.175	1	80	.003
LMAF (mm)	.982	1.475	1	80	.228
BMAF (mm)	.860	12.996	1	80	.001
TH (mm)	.962	3.176	1	80	.079
HH (mm)	.938	5.312	1	80	.024
TRB (mm)	.966	2.845	1	80	.096
TRL (mm)	.988	.943	1	80	.334

KEYS:

TL-Talus length

TW-Talus width

HNL-Head-neck length

LPAS-Length of posterior articular surface

BPAS-Breadth of posterior articular surface

BMAF-Breadth of medial-anterior articular facet

TH-Talus height

HH-Head height

TRB-Trochlear breadth

TRL-Trochlear length

LMAF-Length of medial-anterior articular facet

From the stepwise Discriminant Function Analysis, the discriminant function model for this research work is given as:

$$Y= -12.643+0.127\ TL(mm) + 0.028\ TW(mm) + 0.025\ HNL(mm) - 0.91\ LPAS(mm) + 0.209\ BPAS(mm) + 0.022\ LMAF(mm) + 0.246\ BMAF(mm) - 0.12\ TH(mm) + 0.066\ HH(mm) - 0.033\ TRB(mm) - 0.082\ TRL(mm)$$

(Table 2).

The discriminant analysis predicted that all the measurements on the Tali bones whose discriminant function is closer to 0.690 were probably for males while those that are closer to -1.1025 were probably for females (Figure 2 and 3). Thus, this study figured out the particular sex category each talus fits in by calculating a cut score halfway between the two centroids:

Cut score= (-1.025+0.690)/2 = -0.1675

From the male and female tali mean graphs, it can be noted that the graphs are not skewed which indicates that the data calculations from the stepwise analysis were accurate. Skewed graphs connote an error in any data analysis. (Figure 2 &3)

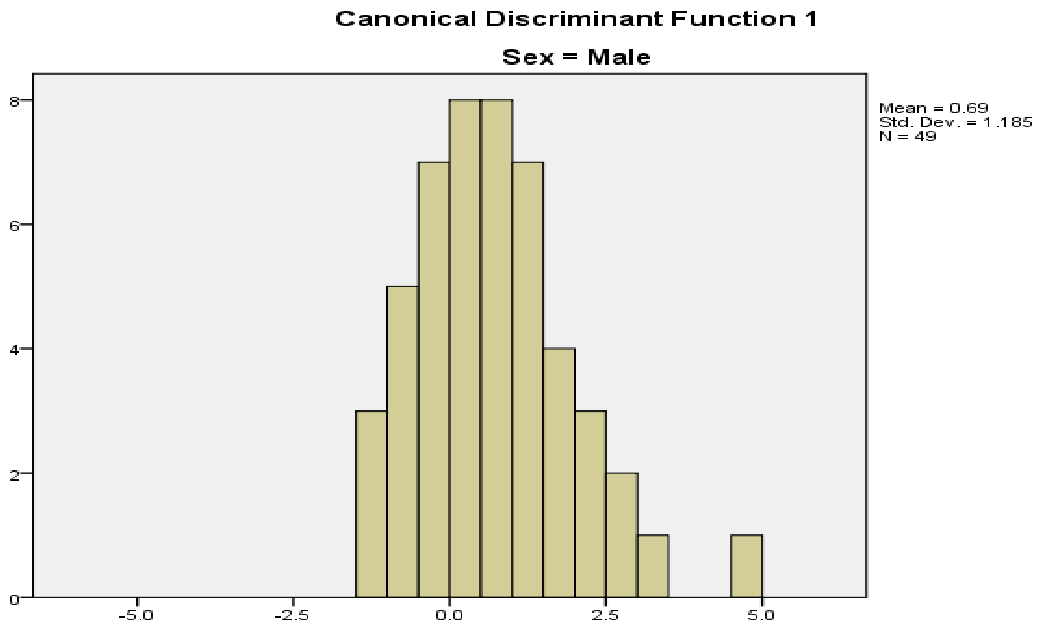

Figure 2: Mean graph showing all the measurements on male tali bones

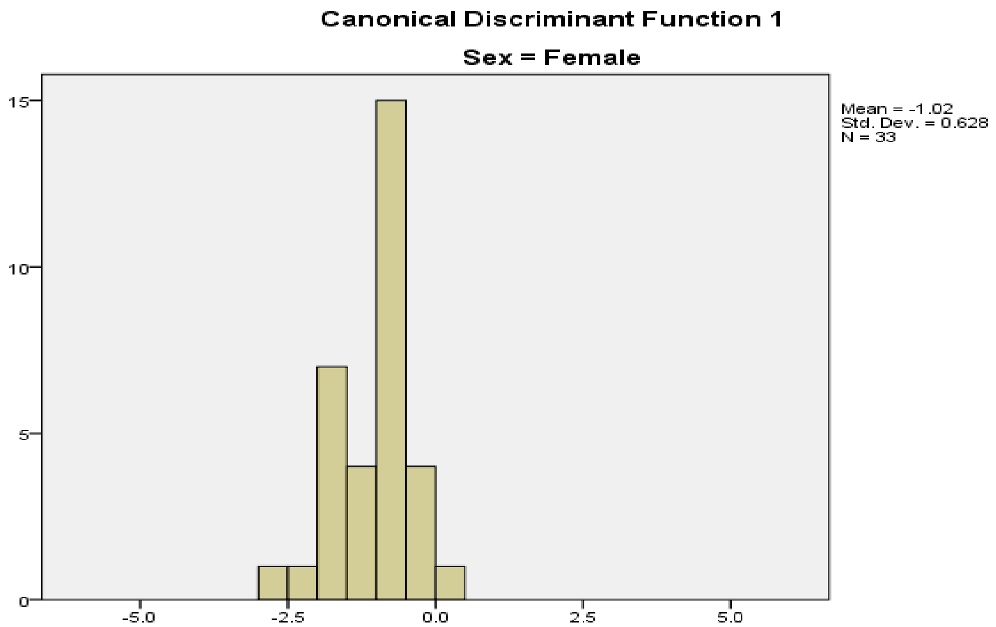

Figure 3: Mean graph showing all the measurements on female tali bones

Thus, the Discriminant Function Analysis correctly classifies more than 70% of the bones (table 3). In overall, 80.5% of the bones were correctly classified into males and females. 35 out of 49 male tali were correctly classified (71%) and 31 of the 33 female tali were correctly classified (94%) (Table 3).

Table 3: Final table from the stepwise discriminant analysis which shows the results classifying the tali bones into sex.

		Sex	Predicted Group Membership		Total
			Male	Female	
Original	Count	Male	35	14	49
		Female	2	31	33
	%	Male	71.4	28.6	100.0
		Female	6.1	93.9	100.0
Cross-validated	Count	Male	34	15	49
		Female	5	28	33
	%	Male	69.4	30.6	100.0
		Female	15.2	84.8	100.0

KEYS:

a. 80.5% of originally grouped cases are correctly classified.
b. Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.

DISCUSSION

All eleven parameters measured on the eighty-two (82) tali bones used in this study showed statistically significant sex differences between males and females, indicating that the talus is sexually dimorphic. The discriminant function equation derived for this study was;

Y= -12.643+0.127TL(mm) + 0.028TW(mm) + 0.025HNL(mm) – 0.91LPAS(mm) + 0.209BPAS(mm) + 0.022LMAF(mm) + 0.246BMAF(mm) – 0.12TH(mm) + 0.066HH(mm) – 0.033TRB(mm) – 0.082TRL(mm).

Similar conclusions were cited by Bidmos and Dayal, Murphy, Gualdi-Russo, and Lee *et al.*, whose discriminant function equation was;

Y= (0.237 * TL) + (0.164 * HNL) + (0.015 * TrL) + (0.025 * LPAS) + (0.024 * TW) + (-0.015 * TrB) + (-0.024 * BPAS) + (0.043 * HH) + (-0.098 * TH) + 18.741) [9,10,2,11].

This current study justified that a single parameter has value for sex determination. Hence, Talus Length (TL) is the said parameter; this is consistent with the study by Bidmos and Dayal, who also found Talus Length (TL) to be the single parameter that served value for sex determination[9]. However, research by Steele, concluded that a single parameter has little practical value for sex determination because of the large overlap of the ranges between the tali measurements of different sexes[5].

In this current study, the tali mean value for males (61.18 millimeters) was found to be greater than that of females (53.35 millimeters). This is consistent with the study by Murphy[10], Gualdi-Russo[2], Bidmos and Dayal [9], whose tali mean value was 51.68 millimeters for males and 47.07 millimeters for females.

In this study, the accuracy rate derived from using Discriminant Function Analysis was 71% (male) and 94% (Female) which was very similar to the results of white South Africans (80% and 81.7%)[9], Black South Africans (80% and 85.8%)[9] and Koreans (67.1% and 82.9%)[11].

The Tali Length (TL) was shown to be the best discriminator of sexual dimorphism after the whole stepwise analysis. This is similar to another study amongst Prehistoric Native Americans[12], Prehistoric New Zealand[10], white South Africans[9], 18th Century British, and European-Americans[13], Northern Italians[2], and on Egyptian population[14].

However, there were other studies whose best discriminator for tali sex determination was the Head Height (HH) and Talus Height (TH). They include; Prehistoric Native Americans[15], black South Africans[10], Length of Posterior Articular Surface (LPAS) in Koreans[12] and MaxTrLg in Thai populations[16]. These differences may be explained by genetics, physical activities performed by different sexes, and variation in stature.

Conclusion

The study found high accuracy rates for determining sex from dry tali bones in Nigeria, recommending discriminant function analysis as a preferred method. Tali Length (TL) also showed high accuracy, making it suitable for forensic situations.

Acknowledgements

The authors acknowledged the efforts of the museum and laboratory attendants in helping us to gather the bones.

Conflicts of Interest: The authors declare that there is no conflict of interest.

REFERENCES

1. Sharon SS, Raja RG. Determination of sex from the talus of the Indian population using morphometrical analysis. International Journal of Pharma and Biosciences. 2016;(7):732-739
2. Gualdi-Russo E. Sex determination from the talus and calcaneus measurements. Forensic Sci. Inter. 2007; 171 (2-3): 151 - 156.
3. Safont S, Malgosa A, Subira ME. Sex assessment based on long bone circumference. American Journal of Physical Anthropology. 2000; 113: 317–328.
4. Waldron T. The relative survival of the human skeleton: implications for palaeopathology. In: Death Decay and Reconstruction: Approaches to Archaeology and Forensic Science. Boddington A, Garland AN, Janaway RC. (eds.) Manchester University Press, Manchester. 1987;101-110
5. Steele DG. The estimation of sex on the basis of Sex Assessment from Talus and Calcaneus 47 the talus and calcaneus. American Journal of Physical Anthropology. 1976; 45:581–588.
6. Hoover K. Carpals and tarsals: discriminant functions for the estimation of sex. Master's Thesis, Florida State University. 1997.
7. Bidmos MA, Asala SA. Sexual dimorphism of the calcaneus of South African Blacks. Journal of Forensic Science. 2004; 49:446–450.
8. Otong ES, Rufai A, Amaza DS, Mustapha Z, Jacks T, Martha O. Estimation of sex using antero-posterior dimension of talus in northeastern Nigeria. British Journal of Medicine and Medical Research. 2016; 14:1-8.
9. Bidmos MA, Dayal MR. Further evidence to show population specificity of discriminant function equations for sex determination using the talus of South African blacks. Journal of Forensic Sciences. 2004; 49(6):1165e70.
10. Murphy AMC. The talus: sex assessment of prehistoric New Zealand Polynesian skeletal remains. Forensic Science International. 2002; 128:155–158.
11. Lee UY, Han SH, Park DK, Kim YS, Kim DI, Chung IH, et al. Sex determination from the talus of Koreans by discriminant function analysis. Journal of Forensic Sciences. 2012; 57(1):166-71.
12. Wilbur AK. The utility of hand and foot bones for the determination of sex and the estimation of stature in a prehistoric population from west-central Illinois. International Journal of Osteoarchaeology. 1998; 8:180e91.
13. Ferrari J, Hopkinson DA, Linney AD. Size and shape differences between male and female foot bones. Journal of the American Medical Association. 2004; 94:434-452.
14. Abd-elaleem SA, Abd-Elhameed M, Ewis AA. Talus measurements as a diagnostic tool for sexual dimorphism in the Egyptian population. Journal of Forensic and Legal Medicine. 2012; 19(2):70-76.
15. Barrett C, Cavallari W, Sciulli PW. Estimation of sex from the talus in prehistoric Native Americans. Collegium Antropologicum. 2001;25(1):13-19.
16. Mahakkanukrau P, Praneatpolgrang S, Ruengdit S, Singsuwan P, Duangto P, Case DT. Sex estimation from the talus in a Thai population. Forensic Science International. 2014; 240:152.e1e8.