Forensic Science International xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

Sex determination by discriminant function analysis of the tibia for contemporary Croats

Mario Šlaus [a,b], Željka Bedić [a,*], Davor Strinović [b], Vedrana Petrovečki [b]

[a] Department of Archaeology, Croatian Academy of Sciences and Arts, Ante Kovačića 5, 10 000 Zagreb, Croatia
[b] Department of Forensic Medicine and Criminalistics, School of Medicine, University of Zagreb, Šalata 11, 10 000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 30 May 2012
Received in revised form 8 September 2012
Accepted 20 January 2013
Available online xxx

Keywords:
Forensic anthropology population data
Discriminant function analysis
Tibia
Sex determination
Positive identification
Croatia

ABSTRACT

Previous studies have demonstrated that populations differ from each other in size and proportion, and that these differences can affect metric assessment of sex. This paper establishes standards for determining sex from fragmentary and complete tibiae in the modern Croatian population. Measurements were taken on 180 tibiae (109 male and 71 female) from positively identified victims of the 1991–1995 War in Croatia. Six standard dimensions: length of the tibia (CML), maximum epiphyseal breadth of the proximal tibia (MPEB), maximum epiphyseal breadth of the distal tibia (MDEB), maximum diameter of the tibia at the nutrient foramen (MDNF), transverse diameter of the tibia at the nutrient foramen (TDNF), and circumference of the tibia at the nutrient foramen (CNF), were taken and subjected to different discriminant function analyses. The highest level of accuracy (91.1%) in the analyzed data set was achieved employing the variables: maximum epiphyseal breadth of the proximal tibia, maximum epiphyseal breadth of the distal tibia, maximum diameter of the tibia at the nutrient foramen, transverse diameter of the tibia at the nutrient foramen, and circumference of the tibia at the nutrient foramen. The second highest level of accuracy (90.6%) was achieved using a combination of only three variables: maximum epiphyseal breadth of the proximal tibia, maximum diameter of the tibia at the nutrient foramen, and circumference of the tibia at the nutrient foramen. The lowest accuracy (84.4%) was obtained when only one variable (maximum diameter of the tibia at the nutrient foramen) was employed. The results of this study show that the modern Croatian tibia is a good skeletal component for determining sex. Standardized coefficients of the discriminant functions generated in this study support the results of previous studies that found that breadth dimensions provide better separation of the sexes than length.

1. Introduction

Similar to all wars, the 1991–1995 War in Croatia that followed the dissolution of the former Yugoslavia resulted in enormous suffering, loss of life, and extensive material destruction. The conflict was characterized by executions and mass burials of civilians and military personnel, extensive destruction of private and government property, and the intentional destruction of schools, hospitals, museums and cultural objects [1]. All together, more than 14,000 war related deaths were recorded in Croatia. To deal with this humanitarian crisis, the Croatian Government formed the Committee for Imprisoned and Missing Individuals. Following the reintegration of occupied territories in 1995 the Committee recovered the remains of 4437 individuals. So far, 3561 of these individuals (80.3%) have been identified. The Committee for Imprisoned and Missing Individuals in Croatia is still searching for 1079 missing and forcefully taken individuals [2].

In order to identify missing individuals, forensic scientists use techniques to determine population affinity, age-at-death, sex, stature, and the potential presence of antemortem pathology or trauma. Determining sex is one of the first and most important steps in identifying decomposed corpses or skeletal remains. Two approaches have been used to accomplish this. The first one relies on the visual inspection and evaluation of morphological sex traits specific to various parts of the skeleton, primarily to the pelvis and skull. The second approach relies on discriminant function analysis of skeletal measurements. The main advantage of discriminant function analysis is that it reduces subjective judgment as well as the level of expertise and experience needed for the determination of sex. For this reason, ever since the development of the discriminant function statistic by Fischer [3], physical anthropologists have found it to be an effective quantitative approach to sex determination [4]. The justification of this application is that morphological variation can be better assessed if the skeleton and its parts are considered as a system and analyzed in terms of the

* Corresponding author. Tel.: +385 1 4698 238; fax: +385 1 4856 211.
E-mail addresses: zbedic@hazu.hr, zeljka.bedic@gmail.com (Ž. Bedić).

0379-0738/$ – see front matter © 2013 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.forsciint.2013.01.025

factors that are collectively postulated to explain it [5]. The first studies using this premise were published by Thieme and Schull [6], Hanihara [7] and Giles [8].

Sex determination is amenable to discriminant function analysis based on the assumption that the two sexes will produce a bimodal curve [6]. Hanihara [7] was, for instance, able to obtain an accuracy rate of 90% from a Japanese sample using only three dimensions from the skull. As the pelvis exhibits the most obvious sexual dimorphism of any skeletal component, early studies concentrated on this part of the skeleton. Within the pelvic girdle, the acetabulum and pubic region have received the most attention [9,10]. The use of pubic and ischial lengths alone yields an accuracy of 94–97% in major race groups including American Black and Whites and the Japanese. A serious drawback, however, of discriminant function sexing of the pubic bone is that it is dependent on the preservation of this skeletal element. This part of the pelvis is, however, relatively fragile and is thus often poorly preserved or completely missing from archeological skeletal collections. The same limitation applies to discriminant function sexing of the skull, as it is dependent on complete crania, an occurrence which varies widely in different archeological sites.

Because of these limitations discriminant function formulae have been calculated for numerous other, more robust, skeletal elements including the femur [11,12], tibia [13] and calcaneus and talus [14]. Accuracies for sex prediction vary from one measurement set to another, but most generally fall within the middle to upper 80th to low 90th percentile range [15].

While these results are encouraging, an important consideration that needs to be taken into account is that discriminant function sexing formulae are population specific, and that formulae developed for one population cannot be applied to other populations [12,16–19]. So far, metric analyses of sexual dimorphism for both medieval [20] and modern Croatians [21] have been published for the femur. Similarly, discriminant functions have also been developed for the medieval Croatian tibia [26]. The purpose of this study is to develop discriminant function formulae for determining sex in contemporary Croatians based on measurements of the tibia. The tibia was chosen for two reasons. Firstly it is, following the femur, the second most robust bone in the human skeleton and therefore most likely to resist insult and decomposition. Secondly, numerous previous studies [13,22–26] have shown that there is considerable sexual dimorphism in the tibia, and that this bone can successfully be used to differentiate between the sexes.

2. Materials and methods

The analyzed skeletal remains used in this study comprise of 180 tibiae (109 male and 71 female) from positively identified victims of the 1991–1995 War in Croatia. The identification (achieved by using DNA analysis, antemortem x-rays, and dental records) was conducted in the Department of Forensic Medicine at the School of Medicine, University of Zagreb. Only left bones were used in the analysis. Damaged bones, those with perimortem injuries, as well as those with pathological changes were excluded from the analysis. All socioeconomic categories are represented in the sample. The mean age in the sample was 53.61 years (range from 24 to 72) for males, and 52.44 years (range from 32 to 74) for females.

A total of six tibial dimensions were taken [13,18]:

1. Length of the tibia (CML): The distance from superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus (measured with an osteometric board).
2. Maximum epiphyseal breadth of the proximal tibia (MPEB): The maximum distance between the most laterally projecting points on the medial and lateral condyles of the proximal epiphysis (osteometric board).
3. Maximum epiphyseal breadth of the distal tibia (MDEB): The maximum distance between the two most laterally projecting points on the medial malleolus and the lateral surface of the distal epiphysis inside the fibular notch (osteometric board).
4. Maximum diameter of the tibia at the nutrient foramen (MDNF): The distance between the anterior crest and the posterior surface at the level of the nutrient foramen (sliding caliper).
5. Transverse diameter of the tibia at the nutrient foramen (TDNF): The straight line distance of the medial margin from the interosseous crest (sliding caliper).
6. Circumference of the tibia at the nutrient foramen (CNF): The circumference measured at the level of the nutrient foramen (plastic-covered cloth tape).

Sexual dimorphism was analyzed using unifactorial statistics with the Index Mm/Mf $\times$ 100 where Mm is the average for males and Mf is the average for females. The multifactorial statistics were performed using the discriminant procedure of the statistical package SPSS 14.0. The procedure calculates the pooled within-group covariance matrix, eigenvalues, canonical correlations, Wilk's λ, and significance levels of all generated discriminant functions, values of the standardized and unstandardized discriminant function coefficients and group centroids, as well as the accuracy of the functions.

3. Results

Table 1 shows the descriptive statistics for both sexes, including the means and standard deviations, for each dimension. As expected, the index of sexual dimorphism is always greater than 100 indicating that males have greater tibial dimensions than females. The *F*-ratios for all of the variables additionally indicate that all of these differences are statistically significant ($P < 0.001$). The standard deviations indicate that, with the exception of the length of the tibia, females exhibit slightly more variation than males. The highest value of the index is seen in the maximum diameter of the tibia at the nutrient foramen, which exhibits a difference of 17.36%, while the lowest value is recorded for the condylo-malleolar length of the tibia (10.39%). These results indicate strong sexual dimorphism in the analyzed data set and presuppose that the variables are useful in evaluating metric differences between sexes.

Once the existence of a strong sexual dimorphism was determined, eight discriminant functions were generated. The first, employing all six variables is useful for determining sex from well preserved tibiae. Because, however, skeletal remains recovered from forensic sites frequently exhibit either peri- or postmortem damage, an additional seven discriminant functions were generated to determine sex from fragmentary tibial remains. Sectioning points, and standardized and unstandardized discriminant function coefficients for the eight functions are presented in Table 2.

Standardized coefficients indicate the relative contribution of each variable to the function.

In the first function maximum diameter at the nutritient foramen makes the greatest contribution, followed by maximum epiphyseal breadth of the proximal tibia, and circumference at the nutritient foramen. The transverse diameter at the nutritient foramen contributes the least. Unstandardized coefficients are used for calculating discriminant function scores from the raw data. A discriminant score is obtained by multiplying each variable with its unstandardized coefficient and adding them together along with the constant. If the score is greater than the sectioning point (for the first function this value is -0.265) the individual is

Table 1
Sexual dimorphism and unifactorial statistics of the tibia in the analyzed sample.

Variable (mm)	Males ($N = 109$)		Females ($N = 71$)		Sexual dimorphism	
	M	SD	*M*	SD	Index[a]	F^{*}
CML	389.28	21.36	352.63	19.26	110.39	136.62
MPEB	79.94	3.72	70.56	5.67	113.29	179.95
MDEB	55.64	3.61	49.13	3.74	113.25	136.11
MDNF	37.11	2.52	31.62	2.94	117.36	178.64
TDNF	25.97	2.34	22.63	2.55	114.75	81.60
CNF	99.56	6.38	86.46	7.34	115.15	160.69

[a] Index = male *M*/female *M* $\times$ 100;
[*] All significant at $P < 0.001$.

Please cite this article in press as: M. Šlaus, et al., Sex determination by discriminant function analysis of the tibia for contemporary Croats, Forensic Sci. Int. (2013), http://dx.doi.org/10.1016/j.forsciint.2013.01.025

Table 2
Standardized and unstandardized discriminant function coefficients and sectioning points.

Functions and variables	Stand. Coeff.	Unstand. Coeff.
(1) Tibial length	0.273	0.013
Prox epiphyseal br.	0.477	0.104
Distal epiphyseal br.	0.121	0.033
A-P diameter	0.652	0.242
Transverse diameter	0.060	0.025
Circ at nutrient for.	−0.296	−0.044
Constant		−19.601
Sectioning point		−0.265
(2) Prox epiphyseal br.	0.493	0.108
Distal epiphyseal br.	0.199	0.054
A-P diameter	0.629	0.234
Transverse diameter	−0.005	−0.002
Circ at nutrient for.	−0.092	−0.014
Constant		−17.917
Sectioning point		−0.259
(3) Prox epiphyseal br.	0.619	0.135
A-P diameter	0.664	0.246
Circ at nutrient for.	−0.096	−0.014
Constant		−17.568
Sectioning point		−0.257
(4) A-P diameter	0.709	0.263
Transverse diameter	0.060	0.025
Circ at nutrient for.	0.285	0.042
Constant		−13.776
Sectioning point		−0.219
(5) Prox epiphyseal br.	0.623	0.136
Circ at nutrient for.	0.517	0.076
Constant		−17.573
Sectioning point		−0.2405
(6) Prox epiphyseal br.	1.000	0.218
Constant		−16.626
Sectioning point		−0.216
Demarking point (mm)	Males > 75.25 > females	
(7) Circ at nutrient for.	1.000	0.148
Constant		−13.936
Sectioning point		−0.204
Demarking point (mm)	Males > 93.01 > females	
(8) A-P diameter	1.000	0.371
Constant		−12.973
Sectioning point		0.2945
Demarking point (mm)	Males > 34.37 > females	

considered male, a lower score indicates a female. When a single variable is used (Functions 6–8), two approaches are possible. Unstandardized coefficients are provided to calculate a discriminant score, but it is easier to compare the dimensions of the analyzed specimen to a demarking point. The demarking point is the simple average of the means for each sex. A higher value indicates a male, a lower value a female.

Reclassification of the cases used to develop the functions employing the leave-one-out classification system shows that with fully preserved tibiae in which all six variables can be utilized the overall accuracy for both sexes is 90.0% (Table 3). Somewhat surprisingly a higher accuracy (91.1%) was achieved when one variable (length of the tibia) was left out. A slightly lower accuracy

Table 3
Sexing accuracy for functions 1–8.

Functions and variables	*N*	Males		Females		Average
		%	*N*	%	*N*	
1. All six variables	180	92.7	101/109	90.1	64/71	90.0
2. All except length of the tibia	180	93.6	102/109	88.7	63/71	91.1
3. MPEB + MDNF + CNF	180	92.7	101/109	88.7	63/71	90.6
4. MDNF + TDNF + CNF	180	90.8	99/109	84.5	60/71	87.2
5. MPEB + CNF	180	93.6	102/109	85.9	61/71	88.9
6. MPEB	180	89.0	97/109	85.9	61/71	87.8
7. CNF	180	89.0	97/109	84.5	60/71	87.2
8. MDNF	180	85.3	93/109	83.1	59/71	84.4

but still higher than that achieved employing all six variables (90.6%) was achieved with three variables from the proximal part of the tibia (maximum epiphyseal breadth of the proximal tibia, maximum diameter of the tibia at the nutrient foramen, and circumference of the tibia at the nutrient foramen), while all of the other functions achieved accuracies of between 84.4% and 88.9%. In general, good overall separation is also provided by discriminant functions using a single variable, the most accurate being maximum epiphyseal breadth of the proximal tibia (87.8%).

4. Discussion

This study confirms that the contemporary Croatian tibia is a good skeletal component from which to determine sex. Various combinations of variables yield accuracies ranging from 84.4% to 91.1%. These results are, in principle, similar to those obtained by other researchers. Gonzáles-Reimers et al. [24] obtained highest accuracies (95–98%) in a prehispanic population from the Canary Islands. Holland [25] in the Hamann–Todd Collection and Kieser [23] in the R.A. Dart Collection in South Africa utilizing only the proximal part of the tibiae achieved high accuracies between 85% and 95%. In a composite medieval sample from Croatia Šlaus and Tomičić [26] obtained accuracies from 82% to 92%. The lowest accuracies achieved İşcan and Miller-Shaivitz [18] in the Terry collection (87–90%) and İşcan et al. [22] in the modern inhabitants of Japan (80–89%).

The highest accuracy of sex determination in this study was achieved using a function that included all of the variables except for the length of the tibia. The variables that discriminate best between males and females in this data set, as determined by the values of the standardized coefficients of the discriminant functions are: maximum diameter of the tibia at the nutrient foramen, maximum epiphyseal breadth of the proximal tibia, and circumference of the tibia at the nutrient foramen. These results are in accordance with other studies [18,21–24,26,27] that showed that breadth dimensions provide better separation of the sexes than length dimensions. This may be because of differential bone remodeling between males and females that leads to greater cortical bone development in males during adolescence which remains unchanged throughout adulthood [28]. This differential cortical bone development primarily affects breadth and circumference measurements. İşcan and Miller–Shaivitz [18], Macho [19], and DiBennardo and Taylor [29] suggest that epiphyseal measurements and midshaft circumference are more reliable indicators of sex because the functional demands of weight and musculature concentrate on these parts of the bone.

İşcan et al. [22] noted metrically detectable changes between pre- and post World War II Japanese tibiae and correctly pointed out that temporal changes within a particular population necessitate updating discriminant functions. This is evident when the metric values for the contemporary Croatian tibia are compared with those of the medieval sample [26]. The modern Croatian tibia exhibits a statistically significant increase in all variables in males with the greatest difference noted in the mean values for maximum tibial length – which increased from 382.2 mm to 389.3 mm, and the mean circumference at the nutrient foramen – which increased from 94.3 mm to 99.6 mm. In females the greatest differences were noted in the mean values for the proximal epiphyseal breadth – which increased from 68.4 mm to 70.6 mm, and the mean circumference at the nutrient foramen – which increased from 84.0 mm to 86.5 mm. Previous discriminant function studies of medieval and modern Croatian samples have also demonstrated differences in the dimensions of the femur [20,21], additionally confirming the need for standards specifically calculated for modern populations.

5. Conclusions

As human skeletal remains from forensic contexts are usually not complete, it is necessary to have sex determination techniques applicable to various parts of the body. This paper provides such standards for the modern Croatian population using the dimensions of the tibia. The results obtained permit accurate diagnosis of sex from complete and fragmentary tibiae and thus, on one hand – constitute an important tool for forensic specialists involved in the ongoing identification of victims of the 1991 War in Croatia and various other medico-legal investigations, and on the other – reinforce the need for similar studies in different contemporary populations of the world.

Acknowledgment

This study was financially supported by a grant from the Ministry of Science, Education and Sports of the Republic of Croatia (Grant number 101-197-0677-0670).

References

[1] M. Šlaus, D. Strinović, N. Pećina Šlaus, H. Brkić, D. Baličević, V. Petrovečki, T. Cicvara Pećina, Identification and analysis of human remains recovered from wells from the 1991 War in Croatia, Forensic Sci. Int. 171 (2007) 37–43.
[2] http://www.mobms.hr/ministarstvo/uprava-za-zatocene-i-nestale/hrvatski-model-trazenja-nestalih-osoba.aspx.
[3] R.A. Fischer, The precision of discriminant function, Ann. Eugen. 10 (1940) 422–429.
[4] M.Y. İşcan, Rise of forensic anthropology, Yearb. Phys. Anthropol. 31 (1988) 203–230.
[5] V. Novotny, Sex determination of the pelvic bone: a systems approach, Anthropologie 24 (1986) 197–206.
[6] F.P. Thieme, W.J. Schull, Sex determination from the skeleton, Hum. Biol. 29 (1957) 242–273.
[7] K. Hanihara, Sex diagnosis of Japanese skulls and scapulae by means of discriminant functions, J. Anthropol. Soc. Nippon 67 (1959) 21–27.
[8] E. Giles, Discriminant function sexing of the human skeleton, in: T.D. Stewart (Ed.), Personal Identification in Mass Disaster, National Museum of Natural History, Washington, DC, 1970, pp. 99–107.
[9] M.A. Kelley, Sex determination with fragmented skeletal remains, J. Forensic Sci. 24 (1979) 154–158.
[10] F.P. Schulter-Ellis, L.C. Hayek, Predicting sex and race with an acetabulum-pubis index, Coll. Antropol. 8 (1984) 155–162.
[11] R. DiBennardo, J.V. Taylor, Multiple discriminant function analysis of sex and race in the postcranial skeleton, Am. J. Phys. Anthropol. 61 (1983) 305–314.
[12] M.Y. İşcan, P. Miller-Shaivitz, Determination of sex from the femur in blacks and whites, Coll. Antropol. 8 (1984) 169–177.
[13] M.Y. İşcan, P. Miller-Shaivitz, Determination of sex from the tibia, Am. J. Phys. Anthropol. 64 (1984) 53–58.
[14] D.G. Steele, The estimation of sex on the basis of the talus and calcaneus, Am. J. Phys. Anthropol. 45 (1976) 581–588.
[15] W.M. Krogman, M.Y. İşcan, The Human Skeleton in Forensic Medicine, Charles C. Thomas, Springfield, IL, 1986.
[16] W.H. Birkby, An evaluation of race and sex identification from cranial measurements, Am. J. Phys. Anthropol. 24 (1966) 21–27.
[17] P. Kajanoja, Sex determination of Finnish crania by discriminant function analysis, Am. J. Phys. Anthropol. 24 (1966) 29–34.
[18] M.Y. İşcan, P. Miller-Shaivitz, Discriminant function sexing of the tibia, J. Forensic. Sci. 29 (1984) 1087–1093.
[19] G.A. Macho, Is sexual dimorphism in the femur a ''population specific'' phenomenon, Z Morphol. Anthropol. 78 (1990) 229–242.
[20] M. Šlaus, Discriminant function sexing of fragmentary and complete femora from medieval sites in continental Croatia, Opusc. Archaeol. 21 (1997) 167–175.
[21] M. Šlaus, D. Strinović, J. Škavić, V. Petrovečki, Discriminant function sexing of fragmentary and complete femora: standards for contemporary Croatia, J. Forensic Sci. 48 (2003) 509–512.
[22] M.Y. İşcan, M. Yoshino, S. Kato, Sex determination from the tibia, J. Forensic Sci. 39 (1994) 785–792.
[23] J.A. Kieser, J. Moggi-Cecchi, H.T. Groeneveld, Sex allocation of skeletal material by analysis of the proximal tibia, Forensic Sci. Int. 56 (1992) 29–36.
[24] E. Gonzales-Reimers, J. Velasco-Vazquez, M. Arnay-de-la-Rosa, F. Santolaria-Fernandez, Sex determination by discriminant function analysis of the right tibia in the prehistoric population of the Canary Islands, Forensic Sci. Int. 108 (2000) 165–172.
[25] T.D. Holland, Sex assessment using the proximal tibia, Am. J. Phys. Anthropol. 85 (1991) 221–227.
[26] M. Šlaus, Ž. Tomičić, Discriminant function sexing of fragmentary and complete tibiae from medieval Croatia sites, Forensic Sci. Int. 147 (2005) 147–152.
[27] France D.L., Sexual dimorphism in the human humerus, Ph.D. Dissertation, University of Colorado, Boulder, 1983
[28] T.K. Black III, A new method for assessing the sex of fragmentary skeletal remains: femoral shaft circumference, Am. J. Phys. Anthropol. 48 (1978) 227–232.
[29] R. DiBennardo, J.V. Taylor, Classification and misclassification in sexing the Black femur by discriminant function analysis, Am. J. Phys. Anthropol. 58 (1982) 145–151.