Coll. Antropol. 40 (2016) 1: 17–22
Original scientific paper

Sex Assessment Using the Femur and Tibia in Medieval Skeletal Remains from Ireland: Discriminant Function Analysis

Mario Novak[1,2]

[1] Institute for Anthropological Research, Zagreb, Croatia
[2] School of Archaeology, University College Dublin, Dublin, Ireland

A B S T R A C T

Sex determination based on discriminant function analysis of skeletal measurements is probably the most effective method for assessment of sex in archaeological and contemporary populations due to various reasons, but it also suffers from limitations such as population specificity. In this paper standards for sex assessment from the femur and tibia in the medieval Irish population are presented. Six femoral and six tibial measurements obtained from 56 male and 45 female skeletons were subjected to discriminant function analysis. Average accuracies obtained by this study range between 87.1 and 97%. The highest level of accuracy (97%) was achieved when using combined variables of the femur and tibia (maximum diameter of femoral head and circumference at tibial nutrient foramen), as well as two variables of the tibia (proximal epiphyseal breadth and circumference at nutrient foramen). Discriminant functions using a single variable provided accuracies between 87.1 and 96% with the circumference at the level of the tibial nutrient foramen providing the best separation. High accuracy rates obtained by this research correspond to the data recorded in other studies thus confirming the importance of discriminant function analysis in assessment of sex in both archaeological and forensic contexts.

Key words: *sexual dimorphism, discriminant function analysis, skeletal remains, femur and tibia, archaeological population, Ireland*

Introduction

Sex assessment is probably the most important aspect, besides age estimation, of the anthropological analysis of a human skeleton, from both archaeological and forensic perspectives. Sex determination standards vary between different populations, but may also be influenced by temporal changes within a population, and therefore, it is important that the standards used in one population are not used in another[1].

In skeletal remains sex may be assessed by using three methods: DNA, morphological and anthropometric. DNA method is most reliable[2], but is also the most expensive and time consuming, and especially in archaeological context DNA is often too degraded due to local conditions[3]. The second, morphological method may be significantly hindered by a fragmentation, and even by a complete lack of bones that exhibit the strongest sexual dimorphism in a human skeleton, the skull and the pelvis, but also by the level of expertise and experience needed for the determination of sex. The third approach mostly relies on discriminant function analysis of skeletal measurements. Its main advantage is that it reduces subjective judgment and the level of expertise and experience needed for this type of analysis[4], but it may also be performed on fragmented and partially preserved bones.

Numerous studies have so far been conducted in an attempt to assess sex by using discriminant function analysis of long bones recovered from archaeological contexts, and in most cases the femur[5–10] and tibia[11,12] were used. These bones are most frequently used due to the fact that they are usually preserved in archaeological context as they are less fragile than other bones, and the previous studies have shown that they exhibit pronounced sexual dimorphism. The combination of both femur and tibia was rarely used for sex assessment of adult individuals from both ancient and contemporary populations[1,13]. In this regard, a study was performed with the aim to develop dis-

Received for publication June 28, 2015

criminant function formulae for determining sex in skeletal remains of medieval Irish based on measurements of the femora and tibiae.

Materials and Methods

The study was conducted on 101 complete adult skeletons recovered from five Irish archaeological sites. The use of these sites is dated to the early medieval period, i.e. between the 5th and 12th centuries CE, based on the radiocarbon dates, horizontal and vertical stratigraphy, and recovered artefacts[14–18]. Four sites (Ardsallagh, Augherskea, Claristown, and Collierstown) are located in the eastern part of the country in county Meath while the fifth site (Omey Island) is positioned in the west, in county Galway. The osteoarchaeological analysis was carried out at the School of Archaeology, University College Dublin, and the National Museum of Ireland Collections Resource Centre, Swords. The sex and the age at death of the studied individuals were estimated using standard anthropological methods. Sex was established based on the differences in pelvic (e.g. greater sciatic notch, ventral arch, subpubic concavity, pre-auricular sulcus, and sacro-iliac articulation) and cranial (e.g. the expression of the nuchal crest, mastoid process, supra-orbital margin and ridge, and mental eminence) morphology[19–21]. Age at death was estimated by using pubic symphysis[22] and auricular surface morphology[23], sternal rib end changes[24,25] and ectocranial suture fusion[26]. No distinction between individuals and/or sites in terms of grave goods was established, and consequently, all series in this research were treated as a single entity. According to the results of this analysis out of 101 skeletons 55 were males and 46 were females (Table 1). Left side femora and tibiae were used in the analysis, and those exhibiting signs of trauma, post-mortem damage and/or pathological alterations were excluded from the study.

A total of six femoral and six tibial measurements as defined by Moore-Jansen et al.[27] were taken. Femoral measurements:

1. Maximum length of the femur (MLF) – the distance between the most superior point on the femoral head to the most inferior point on the distal condyles.
2. Epicondylar breadth (EBF) – the distance between the two most laterally projecting points on the epicondyles.
3. Maximum diameter of the femoral head (MDH).
4. Antero-posterior diameter (APDM) – antero-posterior dimension at the femoral midshaft.
5. Transverse diameter (TDM) – transverse dimension at the femoral midshaft.
6. Circumference (CMF) – circumference at the femoral midshaft.

Tibial measurements:

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.
2. Proximal epiphyseal breadth (MPEB) – maximum width of the proximal end of the tibia.
3. Distal epiphyseal breadth (MDEB) – maximum width of the distal end of the tibia.
4. Maximum diameter at the nutrient foramen (MDNF) – maximum diameter at the level of the tibial nutrient foramen.
5. Transverse diameter at the nutrient foramen (TDNF) – transverse diameter at the level of the tibial nutrient foramen.
6. Circumference at the nutrient foramen (CNF) – circumference at the level of the tibial nutrient foramen.

All measurements were taken by one individual (the author) and each measurement was taken twice (when two same measurements did not correspond the third and final measurement was taken). Sexual dimorphism was analysed using univariate statistics with the Index Mm/Mf × 100 where Mm is the average (mean) for males and Mf is the average (mean) for females. The multifactorial statistics were performed by using the discriminant procedure of the software package SPSS 17.0 for Windows. The data for femora and tibiae were analysed separately, and selected variables were subjected to a direct discriminant analysis to calculate specific discriminant function formulae for some of the parameters, aimed for use on fragmentary remains. In order to check the accuracy of measurements a cross-validation procedure of the average accuracies by using the leave-one-out classification system was utilised.

TABLE 1
SEX AND AGE DISTRIBUTION IN THE STUDIED SAMPLE

Age group	Number of individuals studied		
	Males	Females	Total
18–35	19	18	37
36–50	24	20	44
50+	12	8	20
Total	55	46	101

Results

The descriptive statistics for both sexes, including the means and standard deviations for each dimension, are shown in Table 2. The sexual dimorphism index is greater than 100 in all cases indicating that males have greater femoral and tibial dimensions in comparison to females, while the F-ratios for all analysed variables indicate that all of the differences are statistically significant at $P<0.001$. According to the standard deviations males exhibit more variation, with only exceptions found in the length of the femur and circumference at the level of the tibial nutrient foramen. The highest index value in the

TABLE 2
UNIVARIATE STATISTICS AND SEXUAL DIMORPHISM FOR THE FEMUR AND TIBIA

Variables (mm)	Males (N=55)		Females (N=46)		Sexual dimorphism	
	Mean	SD	Mean	SD	*F*-ratio	Index
Femur						
MLF	461.15	22.89	419.28	24.93	77.25	109.98
EBF	83.45	4.36	73.00	3.91	158.22	114.31
MDH	48.78	2.68	42.02	2.15	189.40	116.09
APDM	30.00	2.40	26.46	1.94	64.68	113.38
TDM	28.84	1.80	24.76	1.58	143.07	116.48
CMF	92.11	5.28	80.98	4.59	125.08	113.74
Tibia						
CML	370.02	27.68	340.09	22.64	35.37	108.80
MPEB	78.22	4.02	68.24	3.86	160.17	114.62
MDEB	56.62	3.48	49.39	2.64	134.09	114.64
MDNF	37.29	2.63	31.28	2.34	144.63	119.21
TDNF	24.82	2.08	20.83	1.58	113.96	119.15
CNF	100.42	5.49	84.22	5.57	215.30	119.23

*All significant at P<0.001

femur is present in the transverse dimension at midshaft (difference of 16.48%), while the lowest value was recorded in the maximum femoral length (9.98%); in the tibia the highest index value is seen in the circumference at nutrient foramen (19.23% difference), and the lowest in the tibial length (8.8%). These results point to a pronounced sexual dimorphism thus indicating that these variables are useful in assessing metric differences between adult males and females from the studied sample.

After a strong sexual dimorphism was established, nine discriminant functions for the femur, tibia, and femur and tibia combined were generated. The first (femur) and the second (tibia) function employ all six variables, but considering that human skeletal material from archaeological contexts is frequently characterised by extensive post-mortem damage, additional functions were generated in order to determine sex from fragmentary remains. Table 3 presents raw and standardized discriminant function coefficients as well as the sectioning points for all nine functions. The standardized coefficients indicate how much each variable contributes to the function relative to other variables. Antero-posterior diameter at midshaft added the most in Function 1, while in Function 2 circumference at nutrient foramen makes the largest contribution. Raw coefficients are used for calculating discriminant function scores from the raw data. The score is calculated in a way that each dimension is multiplied by its raw coefficient and added together along with the constant. Values larger than the sectioning point (for Function 1 this value is –0.1415, and for Function 2 it is –0.1445) give a greater probability that the individual is a male, while lower values give a greater probability that it is a female. Reliabil-

TABLE 3
RAW AND STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS, SECTIONING AND DEMARKING POINTS FOR THE FEMUR AND TIBIA, AND FEMUR AND TIBIA COMBINED

Functions and variables	Standardized coefficient	Raw coefficient
1) MLF	–0.219	–0.009
EBF	0.344	0.083
MDH	0.492	0.200
APDM	0.310	0.141
TDM	0.586	0.344
CMF	–0.251	–0.50
Constant		–20.459
Sectioning point		–0.1415
2) CML	–0.394	–0.15
MPEB	0.388	0.098
MPED	0.098	0.031
MDNF	0.049	0.019
TDNF	0.177	0.095
CNF	0.688	0.125
Constant		–17.851
Sectioning point		–0.1445
3) CNF	0.634	0.115
MDH	0.530	0.216
Constant		–20.538
Sectioning point		–0.148
4) MDH	0.691	0.281
APDM	0.475	0.279
Constant		–20.368
Sectioning point		–0.135
5) MDH	1.000	0.407
Constant		–18.590
Sectioning point		–0.1225
Demarking point	Females<45.70<males	
6) APDM	1.000	0.586
Constant		–15.821
Sectioning point		–0.1065
Demarking point	Females<26.98<males	
7) MPEB	0.375	0.095
CNF	0.722	0.131
Constant		–19.173
Sectioning point		–0.1365
8) MPEB	1.000	0.253
Constant		–18.669
Sectioning point		–0.1125
Demarking point	Females<73.67<males	
9) CNF	1.000	0.181
Constant		–16.836
Sectioning point		–0.1305
Demarking point	Females<93.04<males	

ity increases the further a discriminant score is from the sectioning point. When only single variables are taken into consideration (Functions 5, 6, 8, and 9) the dimensions of the analysed specimen are compared to a demarking point – a higher value gives a greater probability that the individual is a male, and a lower value a female. For example, in case of Function 5 values less than 45.7 for the maximum diameter of the femoral head are more likely to indicate a female individual, while larger values are more likely to indicate a male.

Cross-validation of the average accuracies by using the leave-one-out classification system shows that the accuracy of measurements for both sexes ranges between 87.1 and 97% (Table 4). The combined variables of the femur and tibia (Function 3) provide a highest accuracy of 97% for both sexes, and the same accuracy is achieved when using the combination of the proximal epiphyseal breadth and circumference at nutrient foramen of the tibia. When all six variables are utilised the accuracy slightly drops to 95% for fully preserved femora and 94.1% for fully preserved tibiae. Discriminant functions using a single variable provide accuracies between 87.1 and 96% with the circumference at the level of the tibial nutrient foramen providing the best separation. Classification accuracy was higher in females (reaching accuracy of 100% in Functions 1, 3, and 4) in comparison with males, except in Functions 2 and 8.

Discussion

The present study, as many similar studies before[5,7–9,11–13,29–34], confirms that the femur and tibia alone, but also in combination, are very good skeletal components for determining biological sex in remains of individuals recovered from forensic and archaeological contexts due to a high degree of sexual dimorphism. The obtained accuracy for both sexes in this sample ranges between 87.1 and 97%, which is in accordance with the results recorded by other researchers. When only femur in ancient populations is considered, Özer & Katayama[11] obtained accuracies ranging between 66.9 and 100% in an ancient Japanese population, while Wrobel et al.[13] achieved rates between 77.5 and 98.6% in protohistoric Maya from Belize. In their analysis of fragmentary and complete femora from medieval sites in continental Croatia Šlaus[8] achieved accuracy of 93.75% when using all variables and 91% when using only one variable, while Dittrick & Suchey[6] recorded values of about 90% in prehistoric central California skeletal remains using measurements of the femoral head diameter and bicondylar width. Similar accuracy rates were achieved when only a single femoral dimension was considered[5,7,9]. Furthermore, studies dealing with discriminant functions based on the femur in contemporary populations also revealed high values. For example, an accuracy of 90% was achieved by İşcan & Miller-Shaivitz[30] in the North American skeletal population of known sex and age, while Wu's analysis[31] of contemporary Chinese femora recorded values ranging between 82.3 and 87.2%. This pattern is repeated in other studies as well[1,34].

When only tibial dimensions of ancient human remains are observed, the results recorded in other series are again similar to those observed in this study. Gonzales-Reimers et al.[11] obtained accuracies from 95 to 98% in a prehispanic population from the Canary Islands, Šlaus & Tomičić[12] achieved accuracy ranging between 81.7 and 92.2% in fragmentary and complete tibiae from medieval Croatian sites, while Wrobel et al.[13] observed rates between 87.7 and 93.8%. Again, almost identical values were observed by numerous scholars studying tibial dimensions in contemporary populations[1,24,32,33].

Although discriminant functions based on the combination of the femur and tibia may improve accuracy rates in sex determination[1,13] this type of analysis was rarely used in both archaeological and forensic contexts. In the current study the accuracy of 97% was achieved when using the combination of the femoral head diameter and circumference at nutrient foramen of the tibia. Accuracies of 85.9% (the combination of the femoral maximum antero-posterior diameter and tibial midshaft antero-posterior diameter) and 95.8% (combinations of the femoral head diameter and tibial nutrient foramen antero-posterior diameter, and femoral head diameter and tibial midshaft circumference) were recorded by Wrobel et al.[13] in their study of protohistoric Maya, while Stein & İşcan[1] achieved accuracy of 91.4% using the combination of seven femoral and tibial variables in South African whites. These data, although relatively scarce, testify in favour of using a combination of two or more skeletal elements, particularly when dealing with damaged or partially preserved skeletons.

In the Irish medieval skeletal sample accuracy was higher in females, even reaching 100% in three cases. Males exhibited a wider variation in almost all parameters, except in cases when all six tibial dimensions and the tibial proximal epiphyseal breadth are used. For example, higher accuracies in females were also observed by Stein & İşcan[1], and Gonzales-Reimers et al.[11].

This study clearly showed, the phenomenon already recorded by other researchers[1,5,11,28,29], that width and circumference dimensions provide better separation between

TABLE 4
SEX DETERMINATION ACCURACY RATES IN THE STUDIED SAMPLE

Functions and variables	N	Males		Females		Average
		N	%	N	%	%
1) Femur (all six variables)	101	50/55	90.9	46/46	100	95.0
2) Tibia (all six variables)	101	52/55	94.5	43/46	93.5	94.1
3) CNF + MDH	101	52/55	94.5	46/46	100	97.0
4) MDH + APDM	101	49/55	89.1	46/46	100	94.1
5) MDH	101	49/55	89.1	45/46	97.8	93.1
6) APDM	101	50/55	90.9	43/46	93.5	92.1
7) MPEB + CNF	101	53/55	96.4	45/46	97.8	97.0
8) MPEB	101	48/55	87.3	40/46	87.0	87.1
9) CNF	101	52/55	94.5	45/46	97.8	96.0

the sexes compared to the length measurements. Several authors[28,29,35] suggest that epiphyseal measurements and midshaft circumference are more reliable sex indicators because the functional demands of weight and musculature concentrate on these parts of the bone.

Numerous studies focusing on skeletal remains from different geographic and temporal contexts[1,3,4,7,11,31,34,36] demonstrated that sex determination standards based on anthropometric approach are population specific. When conducting this type of analysis it is of utmost importance to take into consideration geographical provenance of studied remains, and also to bear in mind that standards obtained for contemporary populations may not be used in ancient ones, and vice versa. Therefore, the functions presented in this paper may only be used on human remains retrieved from Irish medieval sites.

Conclusion

The importance of the use of discriminant function analysis in determination of sex of adult individuals is once again confirmed by the study of the femora and tibiae recovered from five Irish medieval sites. High accuracy rates achieved for both males and females correspond to the values observed in other studies dealing with human remains from archaeological and forensic contexts, and testify to the importance of such analyses, particularly in cases when skeletal remains are damaged post-mortem or partially preserved. Although the application of the functions obtained by this research is somewhat reduced by geographic and temporal constraints they will significantly increase the effectiveness of sex determination in medieval skeletal populations from Ireland, especially when used in combination with other methods.

This study was financially supported by the Government of Ireland (Irish Research Council) Postdoctoral Fellowship (GOIPD/2013/1). I wish to thank Prof Mario Šlaus, Prof Ron Pinhasi, Dr René Gapert and Dr Ciarán Brewster for their helpful suggestions. I would also like to thank two anonymous reviewers for their comments that significantly improved the quality of the manuscript. Human skeletal remains presented in this paper are stored at the School of Archaeology University College Dublin and the National Museum of Ireland.

REFERENCES

1. STEIN M, İŞCAN MY, Forensic Sci Int, 90 (1997) 111. — 2. GIBBON V, PAXIMADIS M, STRKALJ G, RUFF P, PENNY C, Forensic Sci Int Genet, 3 (2009) 74. — 3. BAŠIĆ Ž, ANTERIĆ I, VILOVIĆ K, PETAROS A, BOSNAR A, MADŽAR T, POLAŠEK O, ANĐELINOVIĆ Š, Croat Med J, 54 (2013) 272. — 4. ŠLAUS M, BEDIĆ Ž, STRINOVIĆ D, PETROVEČKI V, Forensic Sci Int, 226 (2013) 302. — 5. BLACK III TK, Am J Phys Anthropol, 48 (1978) 227. — 6. DITTRICK J, SUCHEY JM, Am J Phys Anthropol, 70 (1986) 3. — 7. MACLAUGHLIN SM, BRUCE MF, Am J Phys Anthropol, 67 (1985) 413. — 8. ŠLAUS M, Opuscul Archaeol, 21 (1997) 167. — 9. MURPHY AMC, Forensic Sci Int, 154 (2005), 210. — 10. ÖZER İ, KATAYAMA K, Coll Antropol, 32 (2008) 67. — 11. GONZALES-REIMERS E, VELASCO-VAZQUEZ J, ARNAY-DE-LA-ROSA M, SANTOLARIA-FERNANDEZ F, Forensic Sci Int, 108 (2000) 165. — 12. ŠLAUS M, TOMIČIĆ Ž, Forensic Sci Int, 147 (2005) 147. — 13. WROBEL GD, DANFORTH ME, ARMSTRONG C, Anc Mesoam, 13 (2002) 255. — 14. O'KEEFFE T, Mediev Archaeol, 37 (1994) 295. — 15. RUSSELL IR, MOSSOP M, CORCORAN E, Ríocht na Mídhe, 13 (2002) 23. — 16. CLARKE L, Ardsallagh 1: ring-ditch with associated cremations and inhumations. In: BENNETT I, (Ed), Excavations 2006: summary accounts of archaeological excavations in Ireland (Wordwell, Bray, 2009). — 17. O'HARA R, Collierstown 1: a late Iron Age-Early Medieval enclosed cemetery. In: DEEVY MB, MURPHY D, (Eds), Places along the way: first findings on the M3 (National Roads Authority, Dublin, 2009). — 18. BAKER C, Occam's duck: three early medieval settlement cemeteries or ecclesiastical sites?. In: CORLETT C, POTTERTON M, (Eds), Death and burial in early medieval Ireland in the light of recent archaeological excavations (Wordwell, Dublin, 2010). — 19. BASS WM, Human osteology: a laboratory and field manual of the human skeleton (Missouri Archaeological Society, Columbia, 1995). — 20. BUIKSTRA JE, UBELAKER DH, Standards for data collection from human skeletal remains (Arkansas Archaeological Survey, Fayetteville, 1994). — 21. KROGMAN WM, IŞCAN MY, The human skeleton in forensic medicine (CC Thomas, Springfield, 1986). — 22. BROOKS S, SUCHEY JM, Hum Evol, 5 (1990) 227. — 23. LOVEJOY CO, MEINDL RS, PRYZBECK TR, MENSFORTH RP, Am J Phys Anthropol, 68 (1985) 15. — 24. IŞCAN MY, LOTH SR, WRIGHT RK, J Forensic Sci, 29 (1984) 1094. — 25. IŞCAN MY, LOTH SR, WRIGHT RK, J Forensic Sci, 30 (1985) 853. — 26. MEINDL RS, LOVEJOY CO, Am J Phys Anthropol, 68 (1985) 57. — 27. MOORE-JANSEN PH, OUSELY SD, JANTZ RL, Data collection procedures for forensic skeletal material (University of Tennessee, Knoxville, 1994). — 28. İŞCAN MY, MILLER-SHAIVITZ P, J Forensic Sci, 29 (1984) 1087. — 29. DIBENNARDO R, TAYLOR JV, Am J Phys Anthropol, 58 (1982) 145. — 30. İŞCAN MY, MILLER-SHAIVITZ P, Coll Antropol, 8 (1984) 169. — 31. WU L, J Forensic Sci, 34 (1989) 1222. — 32. HOLLAND TD, Am J Phys Anthropol, 85 (1991) 221. — 33. KIESER JA, MOGGI-CECCHI J, GROENEVELD HT, Forensic Sci Int, 56 (1992) 29. — 34. TRANCHO GJ, ROBLEDO B, LÒPEZ-BUEIS I, SÀNCHEZ JA, J Forensic Sci, 42 (1997) 181. — 35. MACHO GA, Z Morphol Anthropol, 78 (1990) 229. — 36. KAJANOJA P, Am J Phys Anthropol, 24 (1966) 29.

M. Novak

Institute for Anthropological Research, Ljudevita Gaja 32, 10000 Zagreb, Croatia
e-mail: mario.novak@inantro.hr

ODREĐIVANJE SPOLA SREDNJOVJEKOVNIH KOSTURNIH OSTATAKA IZ IRSKE NA TEMELJU DIMENZIJA BEDRENE I GOLJENIČNE KOSTI: DISKRIMINACIJSKA ANALIZA

S A Ž E T A K

Određivanje spola koje se temelji na diskriminacijskim analizama ljudskih koštanih ostataka vjerojatno je najučinkovitija metoda određivanja spola u arheološkim i modernim skeletnim uzorcima. No, ta metoda također ima i ograničenja kao što je populacijska specifičnost. U ovom radu predstavljeni su standardi za odredivanje spola srednjovjekovnih kosturnih ostataka iz Irske na temelju dimenzija bedrene i goljenične kosti. Šest bedrenih i šest goljeničnih mjera dobivenih analizom 56 muških i 45 ženskih kostura podvrgnuti su diskriminacijskim analizama. Prosječna preciznost funkcija dobivenih ovom analizom kreće se u rasponu između 87,1 i 97%. Najviša preciznost (97%) ostvareno je kada su korištene kombinirane varijable bedrene i goljenične kosti (najveći promjer glave bedrene kosti i opseg kod hranidbenog otvora goljenične kosti), kao i dvije varijable goljenične kosti (širina proksimalne epifize i opseg kod hranidbenog otvora). Diskriminacijske funkcije koje su koristile jednu varijablu postigle su preciznost između 87,1 i 96%, a najbolje razdvajanje postignuto je kada se koristio opseg kod hranidbenog otvora goljenične kosti. Visoke preciznosti dobivene ovim istraživanjem sukladne su podacima zabilježenim u drugim analizama čime se potvrđuje važnost diskriminacijskih analiza u određivanju spola u arheološkom i forenzičkom kontekstu.