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A study of sexual dimorphism in the femur among contemporary Bulgarian population

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Abstract

Assessment of sex from femoral dimensions has been tried before in several populations. Studies conducted so far have demonstrated that populations differ from one another in size and proportion. The discriminant formulae developed for determining sex for one population group cannot be applied on another. This study establishes standards for determining sex from complete femurs in a modern Bulgarian population. The sample is composed of 140 femora (82 male and 58 female) from adult individuals born after 1920. Twelve measurements were taken. No statistical difference was found between the right and left side (P > 0.05). The mean values of all measurements were significantly higher in males as compared to females (P < 0.001). The most dimorphic single parameter on the basis of univariate discriminant function analysis was linear dimension - maximum length of femur with 90.0 % accuracy rate for sexing individuals. The combination of maximum length, midshaft circumference and bicondylar breadth according to stepwise discriminant analysis provided the best result with 95.7% accuracy. These findings indicate that linear dimensions such as length are more discriminating than breadth and circumference measurements in long bones, unlike the previous studies. Probably this is due to the influence of specific genetic factors. On the other hand, the current forensic practice whereby criminals dismember the remains of their victims in an attempt to make their identification difficult requires that simple methods of sex determination from fragmented skeletal remains are available to forensic anthropologists and skeletal biologists. The head of the femur and the distal femur are an example of such bone fragments. Identification and demarking points have been derived from the maximum diameter of the head and the distal epiphyseal breadth of the femur and used to determine the

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sex of individuals. The objectives of the present study were therefore to establish the standard numerical values of the identification and demarking points for sex determination in Bulgaria. The maximum head diameter and the distal epiphyseal breadth identification point and demarking point were found to be sexually dimorphic. The numerical values of the male identification and demarking points were higher than the corresponding female values.

Keywords: *Forensic anthropology, sexual dimorphism, femur, Bulgarian population, discriminant function analysis.*

Introduction

One of the main goals of forensic anthropology is sex determination, either from skeletal remains, decomposed or mutilated bodies, or cremains (Krogman et al., 1986). Data concerning the sexing potential of the femur is available in the literature and it is well known that this data varies a great deal according to the population sample from which they have been taken (Alunni-Perret et al., 2008; Taylor and DiBennardo, 1982; Iscan and Miller-Shaivitz, 1984; Holliday and Falsetti, 1999; Asala, 2001; MacLaughlin and Bruce, 1985; Kranioti et al., 2009). These studies all contribute to demonstrate that there is considerable intra- and inter-population variability in femoral dimensions (Lavelle, 1974) and no single standardized formula can be used within all population groups for sexing individuals (Alunni-Perret et al., 2008). This is due to the influence of specific genetics, the environment and socio-cultural factors.

From the above, it is deduced that it is necessary to develop equations from skeletal parts often using Bulgarian population of known sex and age. The aim of this study is to conduct a discriminant analysis of sexual dimorphism based on femoral morphology and to establish standards for this population that will facilitate future forensic identifications. The Bulgarian data is then compared with data similarly from Thai, North American, African, East Asian and Croatian samples and then tested using functions derived from them to determine if population's specific sexing formulas are necessary.

Material and methods

A total of 35 pairs of adult femora (24 males, 11 females) and 105 single femora (58 male, 47 female) of modern Bulgarian population were measured. These bones were collected in the Department of General and Clinical Pathology and Forensic Medicine, Medical University, Plovdiv and the Department of General and Clinical Pathology and Forensic Medicine, Medical University, Varna, Bulgaria. The age and sex of all the specimens were documented. All of the individuals examined in this collection were born after 1920. Bones with femoral prosthesis, cortical bone deterioration, extreme osteophytic activity and diffuse osteoarthritis were excluded.

Twelve measurements were taken. The measurements were made using digital osteometric board, vernier caliper (precision 0,01 mm) and graph paper according to standard procedure recommended by Martin and Saller, 1957 and Brauer, 1988: maximum length (M 1), sagittal midshaft diameter (M 6a), transverse midshaft diameter (M 7a), midshaft circumference (M 8), maximum head diameter, head circumference (M 20), sagittal subtrochanteric diameter (M 10), transverse subtrochanteric diameter (M 9), supero-inferior neck diameter (M 15), distal epiphyseal breadth (M 21), maximum sagittal diameter of the lateral condyle (M 23), maximum sagittal diameter of the medial condyle (M 24). Identification and demarking points for sex determination were determined using the method of Jit and Singh (Jit and Singh, 1966).

Statistical package for social sciences (SPSS 17.0) was used. The protocol was defined as follows: for each pair the femoral parameters were measured on both left and right femora in order to assess if a statistical significant difference between the two sides could be recorded. The Paired simple t-test was used to compare the right and the left sides. In order to minimize measurement error, five measurements for each variable of each side were completed. The smallest and the greatest measurements were excluded. Finally, the mean of the three other values was computed and used to characterize a bone. For each side, the values of the bones were tested for normality of the distribution by the Kolmogorov-Smirnov test. The Independent Samples test for equality of means of male and female independent samples was performed for all measured variables. All measurements that were obtained for all variables were also subjected to discriminant function analysis using univariate, multivariate and stepwise methods.

To assess population differences, cross-population tests were then carried out on the Bulgarian sample using the most accurate formulas derived from each of the groups: Thais (King et al, 1998), Croatians (Šlaus et al., 2005), Chinese (Iscan et al., 1995), American blacks and whites (Iscan et al., 1984), and South African whites (Steyn et al., 1998).

Results

The characteristics of the sex repartition and the age mean value of the population are detailed in Table 1.

The Kolmogorov-Smirnov test could not reject the hypothesis of normality of the distribution of the mean values computed ($P > 0.05$). No statistical difference was found between the right and left side for the mean values computed for both genders ($P > 0.05$), thus, allowing the bones of both sides to be grouped together. However, only one bone, either the left or right, has been included in the database. The mean values of all male variables were significantly greater than those of the females at $P < 0.001$ (Table 2).

Table 1: Sex repartition and age mean value

Sex	N	%	Age (mean)	Range	SD
Males	82	59	50,55	19 – 83	16,91
Females	58	41	55,88	31 – 82	16,89

N: Number of cases; SD: Standard deviation

Table 2: Summary statistics of variables

Variable	Males		Females		*F* factor	*P* value
	Mean	SD	Mean	SD		
Maximum length	461,77	19,91	411,74	23,24	1,095	<0,001
Sagittal midshaft diameter	30,23	2,75	26,06	2,30	0,975	<0,001
Transverse midshaft diameter	27,67	2,21	24,89	1,78	4,699	<0,001
Midshaft circumference	93,41	5,52	83,00	4,57	1,370	<0,001
Maximum head diameter	48,33	2,53	42,89	2,84	0,314	<0,001
Head circumference	156,24	7,87	138,12	9,23	2,458	<0,001
Sagittal subtrochanteric	27,22	1,98	24,07	2,08	0,335	<0,001
Transverse subtrochanteric diameter	30,48	4,42	27,11	1,99	3,805	<0,001
Supero-inferior neck diameter	34,12	2,51	28,98	3,36	4,452	<0,001
Distal epiphyseal breadth	84,92	4,27	74,62	3,76	2,610	<0,001
Max. sagittal diameter of the lateral condyle	65,46	3,21	58,86	3,42	0,064	<0,001
Max. sagittal diameter of the medial condyle	64,90	3,37	58,01	3,84	1,128	<0,001

N: Number of cases; SD: Standard deviation

Table 3: Identification and demarking points for sex determination

Variable	Maximum head diameter		Distal epiphyseal breadth	
Gender	Male	Female	Male	Female
N	82	58	82	58
Range	42-53	36-48	77-94	67-84
IP	48	42	84	77
DP	50,88	39,82	85,72	72,34
Rate of sex determination	8,8%	5,8%	23,4%	8,2%

IP: Identification point; DP: Demarking point

Table 4: Univariate discriminant function coefficients and sectioning points

Function variable*	Unstandardized coefficient*	Discriminant function coefficient*	Male group centroids	Female group centroids	Sectioning point* M+F/2	Percentage identified
Maximum length	0,047	20,654	M=0,971	F= - 1,372	-0,200	**90,0**
Sagittal midshaft diameter	0,388	-11,058	M=0,670	F= - 0,947	0,138	80,7
Transverse midshaft diameter	0,489	-12,960	M=0,563	F= - 0,796	-0,116	73,6
Midshaft circumference	0,194	-17,282	M=0,836	F= - 1,182	-0,173	86,4
Maximum head diameter	0,375	-17,281	M=0,845	F= - 1,195	-0,175	85,0
Head circumference	0,118	-17,574	M=0,887	F= - 1,254	-0,185	85,7
Sagittal subtrochanteric diameter	0,494	-12,797	M=0,887	F= - 1,250	-0,133	72,1
Transverse subtrochanteric diam.	0,276	-8,027	M=0,386	F= - 0,546	-0,08	79,3
Supero-inferior neck diameter	0,345	-11,050	M=0,735	F= - 1,040	-0,152	85,0
Distal epiphyseal breadth	0,246	-19,812	M=1,048	F= - 1,482	-0,217	**88,6**
Maximum sagittal diameter of the lateral condyle	0,303	-19,003	M=0,828	F= - 1,171	-0,171	80,0
Maximum sagittal diameter of the medial condyle	0,280	-17,344	M=0,798	F= - 1,128	-0,165	80,7

* Parameters used in formulating function score equations; M: male, F: female

The male identification and demarking points were higher than the corresponding female. The percentages of femurs that were sexed by the both demarking point options—demarking point from maximum head diameter (MHD) and demarking point from distal epiphyseal breadth (DEB) are shown in Table 3. The use of DEB achieves a sexing rate of 23.4 % while a similar use of MHD achieves a sexing rate of 8.8%.

Univariate analysis

Table 4 shows the twelve measured variables and their corresponding un-standardized coefficients, constants and male and female group centroids. The mean value of each variable, its unstandardized coefficient and constant are used to formulate the corresponding discriminant function score equations, into which independent measured variables from unknown femurs may be substituted for sex identification. When the product of the predictor variable and its coefficient added to the constant is above sectioning point classify an individual as male and below as female. The percentage of identification of sex of the selected femur sample is highest for the maximum length of the femur (90.0%). The head circumference gave the highest percentage (85.7%) of sex identification of the upper end of the femur. The distal epiphyseal breadth gave the highest percentage (88.6%) of sex identification of the lower end of the femur.

Multivariate (combined) analysis

The coefficients, constant and sectioning point for formulating the discriminant function score equation are shown in Table 5. The standardized coefficients indicate the relative importance of each variable in contributing to discrimination between the groups, the higher the coefficient the more it contributes to the discriminant score relative to the other variables. It conveys the importance of each variable to the function as conditioned by the presence of the other variables (Purkait, 2005). Thus, the distal epiphyseal breadth has the maximum discriminating power. The structure coefficient gives an idea as to what a variable contributes to a function on its own. It defines the relationship between the function and the variables irrespective of the group difference (Purkait, 2005). The distal epiphyseal breadth also has the highest contribution. The percentage of sex identification by this method was 93.6%.

Table 5: Multivariate (combined) discriminant function coefficients and sectioning points

Function variable*	Unstandardized coefficient*	Standardized coefficient*	Structure coefficient*	Constant*	Group centroids (M+F/2)	Sectioning point*	Percentage classified
Maximum length	0,022	0,475	0,779	-23,522	M=1,246 F= -1,762	-0,258	**93,6**
Sagittal midshaft diameter	0,056	0,145	0,517				
Transverse midshaft diameter	0,039	0,080	0,452				
Midshaft circumference	0,040	0,207	0,671				
Maximum head diameter	0,048	0,128	0,678				
Head circumference	-0,026	-0,216	0,712				
Sagittal subtrochanteric diameter	-0,072	-0,146	0,517				
Transverse subtrochanteric dia.	-0,008	-0,028	0,310				
Supero-inferior neck diameter	0,065	0,189	0,590				
Distal epiphyseal breadth	0,166	0,677	0,841				
Maximum sagittal diameter of the lateral condyle	-0,061	-0,201	0,665				
Maximum sagittal diameter of the medial condyle	-0,008	-0,029	0,640				

* Parameters used in formulating function score equation; M - male, F - female

Stepwise analysis

The results of this analysis are shown in Table 6. The maximum length, distal epiphyseal breadth and midshaft circumference were the three variable selected out of the twelve entered into the analysis for the femur. The combination of these predictors shows the highest accuracy of 95.7%. Table 7 gives the result obtained by

Jack knife method. The procedure was applied using this combination, because it provided the highest percentage of identification of sex. The result of the test supports the original accuracy (fairly equal result, 95.0% vs. 95.7% in the original analysis).

Table 6: Multivariate (stepwise) discriminant function coefficients and sectioning points

Function variable*	Unstandardized coefficient*	Standardized coefficient	Wilk's lambda	Structure coefficient	Constant*	Group centroids *(M+F/2)	Sectioning Point	Percentage classified
Distal epiphyseal breadth	0,136	0,552	0,378	0,865	-24,243	M=1,211 F= -1,712	- 0,2505	**95,7**
Maximum length	0,019	0,397	0,348	0,802				
Midshaft circumference	0,057	0,295	0,337	0,690				

* Parameters used in formulating function score equation; M: male, F: female

Table 7: Results of jackknife procedure

Function	Males %	Males %	Females %	Females %	Percentage identified
	Classified	Misclassified	Classified	Misclassified	
Distal Epiphyseal Breadth + maximum length + midshaft circumference	93,9 % (N=77)	6,1 % (N=5)	96,6 % (N=56)	3,4 % (N=2)	**95,0**

N: Number of cases

Cross-population

The best results are from South African white and American black derived formulas (81% in males and 93.1% in females; 92.6% in males and 87.9% in females). Nevertheless these percentages are lower than those obtained in our original study based on three dimensions—maximum length, distal epiphyseal breadth and midshaft circumference (Table 8).

Discussion

All twelve measurements of the femur show the presence of sexual dimorphism. The results of our study confirm that the femur of individuals from the contemporary Bulgarian population is a good sex predictor with classification accuracy reaching 95.7%. Stepwise discriminant function analysis selected three independent variables, maximum length, distal epiphyseal breadth and midshaft circumference, to achieve this sex determination. The most dimorphic single measurement on the basis of univariate discriminant analysis is a linear dimension—maximum length of femur with 90.0% accuracy rate for sexing individuals. It should be noted that the present finding is opposite to previous studies of long bones in several populations which found that circumference and breath dimensions provide the highest sex separation (Krogman and Iscan, 1996; Alunni-Perret et al, 2008; Iscan and Miller-Shaivitz, 1984; King et al, 1998; Šlaus and Tomičić, 2005; Iscan and Ding, 1995; Steyn and Iscan, 1998).

Our results are also contrary to the findings of Ruff et al 1994, according to which the contemporary long bone is less pronounced variability in diaphysis than its epiphysis, because of the influence of specific socio-cultural factors. With the help of the study of William and Felts, 1959 this fact may be explained by approximately same lifestyle of the men and women, nowadays and specific genetic differences between sexes. According to them, the development of the general features of long bone size and shape depends on genetic factors while the manifestation of its characteristics" depends on the mechanical environment. At the lower end of the femur, distal breadth is the most successful in sex identification (88.6%). In the upper end, and circumference of the head is the most successful in sex determination (85.7%). The lower end is overall more successful in sex identification than the upper end of the femora. This is also confirmed by the results obtained from the demarking points.

Table 8: Cross-test of sex determination accuracy using discriminant function formulas derived from four geographically diverse populations

Cross validation and comparative group	Total N	Male %	Female %	Dimensions in function
Present study	140	95,1%	96,6%	distal epiphyseal breadth + maximum length + midshaft circumference
Thai formula on Bulgarian	140	100%	41,3%	distal epiphyseal breadth + maximum head diameter
Thais original study	104	94,2%	94,1%	
Chinese formula on Bulgarian	140	100%	58,6%	distal epiphyseal breadth + midshaft circumference
Chinese original Study	76	94,6%	94,9%	
S African white formula on Bulgarian	140	81%	93,1%	maximum head diameter + distal epiphyseal breadth + transverse midshaft diameter
S African white original study	105	85,7%	91,8%	
American white formula on Bulgarian	140	0%	100%	maximum head diameter + distal epiphyseal breadth + maximum length + midshaft circumference
Am white original study	101	91,1 %	92,6 %	
American black formula on Bulgarian	140	92,6%	87,9%	maximum head diameter + distal epiphyseal breadth + maximum length + midshaft circumference + sagittal midshaft diameter
American black original study	103	92%	93,4%	
Croatian formula on Bulgarian	140	73%	89,6%	maximum head diameter + distal epiphyseal breadth
Croatian original study	195	92.3%	96.7%	

The bad results of cross-population tests are evidence of the need for creation of the population-specific standards. The present findings agree with previous cross-population studies of King et al, 1998.

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