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Determination of sex from femora

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Abstract

The determination of sex from bones or bone fragments considerably contributes to identifying unknown bodies or skeletal remains. Due to temporal change and regional differences anthropometric standards have to be constantly renewed. The present study provides measurements of femoral dimensions in a contemporary German population and analyses sexual dimorphism by discriminant analysis. Maximum length (male: 46.4±2.4 cm, female: 43.4±2.4 cm), maximum midshaft diameter (male: 3.1±0.2 cm, female: 2.8±0.2 cm), condylar width (male: 8.4±1.0 cm, female: 7.7±0.5 cm), vertical head diameter (male: 4.9±0.3 cm, female: 4.4±0.3 cm), head circumference (male: 15.7±0.8 cm, female: 13.8±1.0 cm) and transverse head diameter (male: 4.9±0.3 cm, female: 4.3±0.3 cm) were measured in 170 femora, 100 from male (age: 16–92 years, mean: 60.8 years; body height: 153–190 cm, mean: 171 cm) and 70 from female (age: 20–96 years, mean: 72 years; body height: 146–175 cm, mean: 161 cm) individuals. In the discriminant analysis (leave-one-out-method) 67.7% of cases could be grouped correctly with the maximum length alone, 72.4% with the maximum midshaft diameter, 81.4% with the condylar width, 86.8% with the vertical head diameter, 87.7% with the head circumference and 89.6% with the transverse head diameter. The stepwise procedure with all head measurements showed that the results for the transverse head diameter could not be improved. With all measurements subjected to stepwise procedure 91.7% of cases could be classified correctly combining midshaft diameter and head circumference (D=3.012×midshaft diameter in cm+0.780×head circumference in cm 20.569).

Keywords: Identification; Sex determination; Femur; Discriminant analysis

1. Introduction

Determining sex is one of the first and most important steps in identifying decomposed corpses or skeletal remains. It is important to gain data on the sexual dimorphism of many bone dimensions in order to be able to assess sex in case only parts of corpses are found. As commonly accepted anthropometric standards considerably vary among different populations, they also have to be constantly renewed to cope with temporal change.

Various studies dealing with determining sex from femoral measurements can be cited from the anthropological and forensic literature. Steyn and Iscan [1] investigated femora from a White South African population, Iscan and Shihai [2] and Liu [3] from a Chinese. DiBennardo and Taylor [4] tested a method previously developed by Black [5] in a sample of femora from North American Whites. Schulter-Ellis et al. [6–8] in their investigations on pelvic dimensions mention data for the femoral head diameter in

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North American Blacks, Eskimos, Indians and Whites. Leopold [9,10] cites own measurements of length and vertical head diameter in German individuals. Pons [11] took femoral measurements in a Portugese population. While the above studies are from contemporary samples (some [6–8] are from collections at the Smithonian Institute; some from individuals who died in the 1930s [2] or about the end of the 19th century [11]), MacLaughlin and Bruce [12] analysed the sexual dimorphism of the femoral midshaft diameter in a prehistoric Scottish population.

The present investigation aims at obtaining measurements for six different femoral dimensions (length, head and shaft diameters, distal width) in a contemporary German population. In medico-legal practice statements on the probable sex of an unknown decomposed body are often expected already during the autopsy. Our study was therefore restricted to six relatively easily accessible dimensions. The bones were prepared by removing soft tissues, muscles, tendons and ligaments as can be done in the course of an autopsy; long-lasting complex processes like drying were avoided.

2. Materials and methods

2.1. Material

The sample of the femora for the study came partly from the dissection courses in the years 1994–1997 of the Institute of Anatomy at the University of Cologne and partly from autopsies carried out in the Institute of Legal Medicine at the University of Tübingen since 1990. A total of 170 femora, 100 from male and 70 from female individuals were included in the study; bones with healed fractures or severe degenerative changes were excluded. The mean age of the male individuals was 60.8 years with a minimum of 16 years and a maximum of 92 years. The mean age of the female individuals was 72.4 years with a minimum of 20 and a maximum of 96 years. The mean height was 171.6 cm (range: 153 cm–190 cm) in the males and 161.0 cm (range: 146 cm–175 cm) in the females.

2.2. Method

2.2.1. Measurements

The following dimensions were measured:

- maximum length (number 1 according to Martin and Saller [13])
- maximum midshaft diameter (maximum of antero-posterior and transverse diameter, numbers 6 and 7 according to Martin and Saller [13])
- condylar width (number 21 according to Martin and Saller [13])
- vertical head diameter (number 18 according to Martin and Saller [13])
- transverse head diameter (number 19 according to Martin and Saller [13])
- head circumference (number 20 according to Martin and Saller [13])

The length was taken with an osteometric board, the other dimensions with a calliper rule.

2.2.2. Statistics

The statistical analyses were carried out using the SPSS system.

2.2.3. Univariate statistics

Mean and standard deviation of the independent variables (measurements) were computed. Levene's test was applied indicating that the variances in the two groups (male and female) were equal for all dimensions. Accordingly, the *t*-test for equal variances was applied testing the difference between the means of the two groups. The *t*-value as statistical measure with known random distribution is determined according to the number of the degrees of freedom. A low *P*-value indicates that the null-hypothesis that there is no difference between the means should be refused. The standard error for the difference and the 95%-confidence interval of the difference are computed; the true difference between the means in the overall population lies within the limits of the interval with a probability of 95%.

2.2.4. Discriminant analysis

An affine discriminant function D:

$$D = b_0 + \sum_i b_i X_i$$

is introduced as an auxiliary variable; b_i represent the coefficients, X_i the measured dimensions. High values of D indicate group 1 (male), low values group 2 (female). The means M_1 of group 1 (male), M_2 of group 2 (female) and M of the sample are:

$$M_1 = \sum \{D(\omega_1) \mid \omega_1 \in \Omega_1\}/|\Omega_1|$$

$$M_2 = \sum \{D(\omega_2) \mid \omega_2 \in \Omega_2\}/|\Omega_2|$$

$$M = \sum \{D(\omega) \mid \omega \in \Omega\}/|\Omega|$$

where ω denotes the individuals in the groups and Ω the group.

With the auxiliary quantities Q_B and Q_W:

$$Q_B = \sum_{i=1}^{2} |\Omega_i|(M_i - M)^2$$

$$Q_W = \sum \{(D(\omega_1) - M_1)^2 \mid \omega_1 \in \Omega_1\} + \sum \{(D(\omega_2) - M_2)^2 \mid \omega_2 \in \Omega_2\}$$

the functional:

$$F(b_1, \ldots, b_n) = Q_B/Q_W$$

is derived. It is maximized to obtain estimators $\hat{b}_i$ for the coefficients b_i. Thus, a great variation of D between the groups and a small variation of D within the groups is achieved. The histogram of the random samples of males and females is used to derive an estimator $\hat{P}(D)$ for the probability density function $P(D)$ of the discriminant function D. The sectioning point S for the group discrimination is:

$$\hat{P}(D > S) = 0.5 = \hat{P}(D \leq S)$$

If the value of the discriminant function D is higher than S, the individual is classified as male. If the value of D is lower than S, the individual is classified as female.

The probability that an individual ω belongs to the group Ω_i if its discriminant value is $D(\omega) = d$ is computed according to the theorem of Bayes:

$$\mathrm{P}(\Omega_i \mid D = d) = (\mathrm{P}(D = d \mid \Omega_i)\mathrm{P}(\Omega_i)) \Big/ \left(\sum_{k=1}^{2} \mathrm{P}(D = d \mid \Omega_k)\,\mathrm{P}(\Omega_k)\right)$$

The apriori probability $\mathrm{P}(\Omega_i)$ is assumed to be 0.5 (for male and female); the empirical probabilities $\mathrm{P}(D = d \mid \Omega_i)$ are estimated from the group histograms of the discriminant function of the male and female samples. It is now possible to calculate the probability for an erroneous classification.

A high value for the canonical correlation coefficient:

$$C = \sqrt{Q_B/(Q_B + Q_W)}$$

indicates a good distinction between the groups, a low value an overlapping.

The validation classification was carried out according to the leave-one-out method (jackknifed), which means that each case is classified by discriminant functions derived from the other cases. The discriminant analysis was applied to all measurements singly. Cases with missing values of the relevant variable were excluded.

2.2.5. Stepwise procedure

All dimensions and all three head dimensions were additionally subjected to a stepwise procedure. Let X be the set of all variables. For each set A of possibly included variables and for each variable X in $X \backslash A$ to be tested for inclusion or X in A to be tested for exclusion Wilk's Lambda can be calculated:

$$\lambda = \frac{Q_W}{Q_B + Q_W} = 1 - C^2$$

The test variable of the partial F-test is determined:

$$F = (n - 2 - |A|) \times \left(\frac{1 - \lambda_{A \cup \{X\}}/\lambda_A}{\lambda_{A \cup \{X\}}/\lambda_A}\right) \quad \text{in case of inclusion of } X$$

$$F = (n - 2 - (|A| + 1)) \times \left(\frac{1 - \lambda_A/\lambda_{A \cup \{X\}}}{\lambda_A/\lambda_{A \cup \{X\}}}\right) \quad \text{in case of exclusion of } X$$

with: n: number of cases, λ_A: Wilk's Lambda for the set A of included variables, $\lambda_{A \cup \{X\}}$: Wilk's Lambda for the set $A \cup \{X\}$ of variables.

For each step m of the procedure the following substeps were performed:

1. Inclusion: Check all variables not included in step $m-1$; include that variable whose inclusion minimizes Wilk's Lambda and for which $F > 3.84$.
2. Exclusion: Check all variables accepted for step

Table 1
Univariate statistics[a]

Dimension	Males		Females		t-test				
	Mean [cm]	SD [cm]	Mean [cm]	SD [cm]	t-value	dof	P	SE'_{diff} [cm]	95%-CI_{diff} [cm]
Maximum length	46.4	2.4	43.4	2.4	5.977	94	<0.0005	0.503	2.008–4.005
Midshaft diameter	3.1	0.2	2.8	0.2	6.136	96	<0.0005	0.044	0.186–0.363
Condylar width	8.4	1.0	7.7	0.5	4.007	100	<0.0005	0.174	0.353–1.045
Vertical head diameter	4.9	0.3	4.4	0.3	9.175	104	<0.0005	0.058	0.418–0.648
Transverse head diameter	4.9	0.3	4.3	0.3	10.581	104	<0.0005	0.055	0.478–0.699
Head circumference	15.7	0.8	13.8	1.0	10.435	104	<0.0005	0.180	1.519–2.232

[a] Mean and standard deviation (SD)[cm]; results of t-test: t-value, degrees of freedom (dof), P-value (P), standard error of difference between the means (SE_{diff}), 95%-confidence interval of the difference between the means (95%-CI_{diff}).

m; exclude that variable whose inclusion maximizes Wilk's Lambda and for which $F<2.71$.
3. Stop if neither substep 1 nor substep 2 changes the set of included variables.

Cases with missing values in a variable relevant for the actual analysis step were excluded from the computation of Wilk's Lambda and the F-value.

3. Results

Table 1 presents the means and corresponding standard deviations of the measured dimensions for males and females and the results of the t-test for the equality of means: t-value (t), number of the degrees of freedom (dof), P-value (P), standard error of the difference between the means (SE_{diff}) and 95%-confidence interval for the difference (95%-CI_{diff}). The first six lines of Table 2 give the results of the discriminant analysis for each of the dimensions measured: the unstandardized coefficients b_0 and b_1, the sectioning point (S), the canonical correlation coefficient (C) and the percentage of correctly classified cases. In case of the condylar width, the value of the canonical correlation coefficient was relatively small (0.372) indicating an overlapping

Table 2
Results of discriminant analysis[a]

	b_0	b_1	b_2	S	C	Correctly class.
Maximum length	−18.657	0.413	–	−0.28	0.525	67.7%
Midshaft diameter	−13.747	4.581	–	−0.12	0.531	72.4%
Condylar width	−9.370	1.153	–	−0.08	0.372	81.4%
Vertical head diameter	−16.551	3.489	–	−0.27	0.669	86.8%
Transverse head diameter	−17.133	3.642	–	−0.32	0.720	89.6%
Head circumference	−16.898	1.127	–	−0.29	0.715	87.7%
Midshaft diameter + head circumference	−20.569	3.012	0.780	−0.66	0.784	91.7%

[a] Coefficients of discriminant functions: b_0, b_1, b_2, sectioning point (S), canonical correlation coefficient (C), percentage of correctly classified cases.

Table 3
Course of the stepwise discriminant analysis for all dimensions: In every step the included variables are shown in italics

	Variable	Inclusion		Exclusion	
		F-value	Wilk's Lambda	F-value	Wilk's Lambda
Step 0	Maximum length	16.113	0.672		
	Midshaft diameter	26.821	0.552		
	Condylar width	1.459	0.958		
	Vertical head diameter	33.093	0.499		
	Head circumference	36.085	0.478		
	Transverse head diameter	34.477	0.489		
Step 1	Maximum length	0.056	0.477		
	Midshaft diameter	7.591	0.386		
	Condylar width	0.643	0.468		
	Vertical head diameter	0.431	0.471		
	Head circumference			*36.085*	
	Transverse head diameter	0.067	0.477		
Step 2	Maximum length	0.136	0.384		
	Midshaft diameter			*7.591*	*0.552*
	Condylar width	0.018	0.386		
	Vertical head diameter	0.619	0.379		
	Head circumference			*13.722*	*0.478*
	Transverse head diameter	1.015	0.374		

between the groups; nevertheless the percentage of correct classification was fairly good (81.4%). An explanation for this apparent inconsistency could be the deviation of the probability density function from the Gaussian especially in the female group. The variable can therefore not be recommended for the distinction between the two groups. However this result is only preliminary as it could be a random deviation in our sample. A Kolmogorov-Smirnov procedure, testing the null-hypothesis of Gaussian distribution of the condylar width in the overall male population was highly significant, indicating that the null-hypothesis has to be refused. The same procedure was not significant ($P = 0.2$) for the condylar width in the female population.

Tables 3 and 4 present the course of the stepwise procedure, Table 3 for all dimensions and Table 4 for all head dimensions. The percentage of correctly grouped cases achieved by the transverse head diameter alone could not be improved by analysing all head dimensions stepwise. With all measurements subjected to a stepwise procedure, 91.7% of cases were classified correctly by midshaft diameter and head circumference.

4. Discussion

4.1. Univariate statistics

4.1.1. Maximum length

Steyn and Iscan [1] determined a maximum length

Table 4
Course of the stepwise discriminant analysis for all head dimensions: In every step the included variables are shown in italics

	Dimension	Inclusion		Exclusion	
		F-value	Wilk's Lambda	F-value	Wilk's Lambda
Step 0	Vertical head diameter	84.180	0.553		
	Head circumference	108.893	0.489		
	Tranverse head diameter	111.967	0.482		
Step 1	Vertical head diameter	0.000	0.482		
	Head circumference	0.070	0.481		
	Transverse head diameter			*111.967*	

of 469,68 mm±27.97 (males) and 437.62 mm±20.65 (females) for a contemporary White South African population. Iscan and Shihai [2] obtained a mean length of 442.19 mm±22.9 (males) and 400.97 mm±19.71 (females) in Chinese individuals that died in the 1930s. Liu [3] measured values of 431.3 mm±25.8 (males) and 394.1 mm±15.5 (females) in a contemporary Chinese population. Leopold [9,10] cites own investigations in a German population with a femoral length of 46.9 cm±2.4 in males and 43.3 cm±1.8 in females. DiBennardo and Taylor [4] found values of 450.0 mm±20.4 for males and of 423.0 mm±22.1 for females in contemporary White North American individuals. Pons [11] determined mean values of 443.95 mm in right and 444.69 mm in left femora of males and of 397.42 mm in right and 398.03 mm in left femora of females for Portugese individuals from about the end of the 19th century. Our length measurements for a German population are almost equal to those measured by Steyn and Iscan [1] in White South Africans and to those cited by Leopold [4].

4.1.2. Midshaft diameter

Steyn and Iscan [1] measured an antero-posterior diameter of 31.29 mm±2.61 (males) or 28.18 mm±2.50 (females) and a transverse diameter of 29.11 mm±2.20 (males) or 26.32 mm±1.67 (females). Iscan and Shihai [2] give an antero-posterior diameter of 27.89 mm±2.56 (males) or 24.38 mm±1.93 (females) and a transverse diameter of 25.66 mm±2.76 (males) or 23.23 mm±2.24 (females). Liu [3] found a slightly larger value of 27.0 mm±2.6 for the antero-posterior diameter in males and slightly smaller values for females (23.7 mm±1.7) and for the transverse diameter (26.7 mm±2.2 in males; 24.2 mm±1.7 in females). DiBennardo and Taylor [4] determined values of 29.0 mm±20.4 in males and 27.0 mm±1.7 in females for the antero-posterior and of 28.0 mm±2.2 in males and 25.0 mm±1.7 in females for the transverse diameter. Pons [11] measured a minimum transverse diameter of the diaphysis of 26.13 mm in right and 26.44 mm in left femora of males and of 23.55 mm in right and 23.78 mm in left femora of females. Our measurements of the maximum midshaft diameter are almost equal to those measured by Steyn and Iscan [1] for the antero-posterior diameter.

4.1.3. Condylar width

Steyn and Iscan [1] determined a distal breadth of 84.62 mm±4.63 in males and of 75.10 mm±3.32 in females. Iscan and Shihai [2] measured one of 80.32 mm±4.27 and 70.62 mm±3.20 respectively in Chinese individuals, while Liu [3] gives considerably smaller values of 77.8 mm±5.8 (males) and 69.3 mm±3.0 (females). Pons [11] obtained a width of the lower articulation of 75.60 mm in right and 75.44 mm in left femora of males and of 65.03 mm in right and 64.95 mm in left femora of females. Our values are again almost equal to those measured by Steyn and Iscan [1] for male White South Africans, while they are larger for females.

4.1.4. Head diameter

Steyn and Iscan [1] obtained values of 48.46 mm±2.65 for males and 43.02 mm±2.42 for females. In Chinese individuals, Iscan and Shihai [2] measured a head diameter of 46.16 mm±2.62 (males) and 41.13 mm±2.64 (females) while Liu [3] gives values of 42.7 mm±3.1 and 38.4 mm±1.9 for the vertical and of 44.7 mm±3.2 and 40.0 mm±1.9 for the tranverse diameter. Shulter-Ellis et al. mention values of 48.490 mm±2.7 (males) and 42.940 mm±2.19 (females) for White skeletons from the Terry Collection [7], of 46.763 mm±2.085 (males) and 42.459 mm±2.022 (females) for Eskimo and of 47.190 mm±1.995 (males) and 42.763 mm±2.136 (females) for Indian skeletons from the Smithsonian Institute Collections [8] and of 48.39 mm±2.82 (males) and 42.80 mm±2.00 for Black skeletons from the Terry Collection [6]. Leopold [10] cites own studies with a mean vertical head diameter of 46.8 mm in left and 47 mm in right femora of males and of 40.8 mm in left and of 41.8 mm in right femora of females. Pons [11] determined a mean head diameter of 46.11 mm in right and 46.06 mm in left femora of male and of 39.94 mm in right and 39.87 mm in left femora of female individuals. In contrast to the results of Liu [3] our values for vertical and transverse head diameter do almost not differ; the transverse head diameter in females seems slightly larger. The values are only slightly higher than those by Steyn and Iscan [1]. The measurements by Leopold [10] for German individuals are considerably smaller; they are valid for bone without cartilage.

4.2. Discriminant analysis

Steyn and Iscan [1] achieved a percentage of correctly classified cases of 88.6% with head diameter, transversal and distal breadth, of 85.9% with the head diameter, of 90.5% with the distal breadth and of 88.6% with head diameter and distal breadth. Iscan and Shihai [2] obtained a percentage of correct grouping of 92.3% with distal breadth, length and antero-posterior diameter, of 94.9% with the distal breadth and of 83.1% with the head diameter. Liu [3] proved among other dimensions maximum head diameter, transverse head diameter, epicondylar breadth to be useful for sex diagnosis with discriminant rates of between 80.1 and 85.1%. DiBennardo and Taylor [4] came to a percentage of accurate prediction of 80% with the femoral length. In contrast to the above authors, we could only classify about 67–68% of cases correctly with the maximum length applied alone. Our prediction values with vertical and transverse head diameter of 86.8% and 89.6% are almost equal to those mentioned by Steyn and Iscan [1] for South African Whites; they are higher than those measured by Iscan and Shihai [2] and Liu [3] in Chinese individuals. The condylar width, although providing high percentages of correct classification, cannot be recommended for sex determination, since the low canonical correlation indicates an overlapping between the groups in our sample. The head circumference is not dealt with in the other investigations; in our analyses it produced the second highest percentage of correctly classified cases when applied alone and the highest percentage combined with the midshaft diameter.

The present study provides measurements for six different femoral dimensions easily accessible during autopsy without complex processes of preparation. Emphasizing the differences among different populations, our mean values considerably differed from values measured in e.g. Chinese populations, while they were very similar to measurements for White South Africans. The results of the discriminant analysis were by and large – except for the maximum length if applied singly – good. The results regarding the head diameter dimensions are similar to those to be cited from the literature. Furthermore, the head circumference not mentioned in the literature seems to be useful for sex discrimination.

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