DISCRIMINANT FUNCTION SEXING OF FRAGMENTARY AND COMPLETE FEMORA FROM MEDIEVAL SITES IN CONTINENTAL CROATIA

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Discriminant function analysis for sex assessment was applied to 160 femora from four medieval archaeological sites in continental Croatia. The measurements included femoral length, epicondylar breadth, diameter of the femoral head and two subtrochanteric and two midshaft dimensions. Using all seven variables the procedure correctly assigned sex for 93.75 % of the sample. This compares favorably with results achieved with other skeletal parts; it also compares favorably with results using the femur in sexing other population groups. Discriminant function analysis with only one variable, useful for sexing fragmentary remains, also produced good results. Maximum diameter of the femoral head was the best sex discriminator with an accuracy of 91 %. Epicondylar breadth with an accuracy of 87.5 %, and maximum length of the femur with an accuracy of 85 % are also useful for determining sex in poorly preserved remains. The discriminant function shows both size and shape elements. Prominent among the former is joint size - epicondylar breadth and diameter of the femur head. The shape element includes midshaft and subtrochanteric form. The discriminant function was tested on independent medieval and Late Antique samples from continental Croatia and Dalmatia. Both the multivariate and univariate discriminant functions were very successful with an accuracy of from 87 % to 95 %. Further tests on other Croatian populations are, however, necessary to validate these results and to determine the breadth of applicability of the discriminant functions.

Key words: Discriminant function sexing, femur, medieval Croatia

Introduction

The identification of sex in human skeletal remains is an important component and frequently the starting point of many anthropological investigations. Two approaches have been used to sex unidentified skeletal remains. The first approach relies on the visual inspection and evaluation of morphological sex traits specific to various parts of the skeleton, primarily to the pelvis and skull. Phenice (1969), for instance, observed sexual variation in three aspects of the pubic bone: the ventral arc, subpubic concavity and medial aspect of the ischiopubic ramus which was so pronounced that Phenice stated they provided a correct estimate of sex in about 96% of all cases.

The second approach relies on the 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 (1940), physical anthropologists have found it to be an effective quantitative approach to sex determination. 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 factors that are collectively postulated to explain it (Novotny 1986). The first studies using this premise were published by Thieme and Schull (1957); Hanihara (1959) and Giles (1970).

Sex determination is amenable to discriminant function analysis based on the assumption that the two sexes will produce a bimodal curve (Thieme and

Schull 1957). Hanihara (1959) was, for instance, able to obtain an accuracy rate of 90% from a Japanese sample using only three dimensions from the skull. Because the pelvis exhibits the most obvious sexual dimorphism of any skeletal component, early studies have concentrated in this area. Within the pelvic girdle, the acetabulum and pubic region have received the most attention (e.g. Kelley 1979, Schulter-Ellis and Hayek 1984). The use of pubic and ischial lengths alone yields an accuracy of 94% to 97% in major race groups including American Black and Whites and the Japanese. One serious drawback of discriminant function sexing of the pubic bone, as well as that of Phenices visual inspection method, is that they are dependent on the preservation of the pubic bone. This part of the pelvis is, however, relatively fragile and is thus often poorly preserved or completely missing from archaeological skeletal collections. The same problem applies to discriminant function sexing of the skull which is dependent on complete crania, an occurrence which varies widely in different archaeological sites. Because of these limitations discriminant function formulae have been calculated for numerous other, more robust, skeletal elements including the femur (DiBennardo and Taylor 1979; Iscan and Miller-Shaivitz 1984a), tibia (Iscan and Miller-Shaivitz 1984b) and calcaneus and talus (Steele 1976). 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.

While these results are encouraging, a further consideration which needs to be taken into account is that discriminant function sexing formulas are population specific and that formulas developed for one population cannot be applied to other populations (Birkby 1966; Kajanoja 1966). The purpose of this study is to develop discriminant function formulas for determining sex in medieval Croatian archaeological populations based on metric measurements of the femur. The femur was chosen for two reasons. Firstly, it is the most robust bone in the human skeleton and therefore most likely to resist insult and decomposition. Secondly, previous studies (e.g. Black 1978; Di Bennardo and Taylor 1983; Iscan and Miller-Shaivitz 1984a; MacLaughlin and Bruce 1985) have shown that there is considerable sexual dimorphism in the femur and that this bone can successfully be used to differentiate between the sexes.

Materials and methods

The analyzed sample consists of 160 femora, 80 male and 80 female, from four medieval archaeological sites in continental Croatia. The sites included in this analysis are: Stari Jankovci, a late Avaro-Slav cemetery whose use is dated from the end of the 7th century to the second half of the 8th century (Šmalcelj 1981: 143), Privlaka, a late Avaro-Slav cemetery whose use is dated to the 8th century (Šmalcelj 1973: 118; Šmalcelj 1981: 144), Stenjevac, a medieval cemetery whose use is dated from the 11th to the 13th century (Simoni, personal communication) and Nova Rača, a late medieval cemetery whose use is dated from the 13th to the 17th century (Jakovljević, personal communication). The number of femora from each site is shown in Table 1.

	Male femora	Female femora
St. Jankovci	22	19
Privlaka	18	17
Stenjevac	15	19
Nova Rača	25	25
TOTAL	**80**	**80**

Table 1. The number of femora used in the discriminant function analysis from each site.

Only left bones were used in the analysis. Damaged bones and those with pathological changes were excluded.

In order to evaluate any new method of sex determination, the sex of the individuals represented in the sample must be known, or as in this case, where there are no written records or direct cultural evidence, it must be established by other means. In this case only femora from well preserved and complete skeletons in which sex could be unequivocally assigned based on pelvic and cranial morphology were utilized.

The following measurements were taken on the femora:

1) Maximum length of the femur (MLF): The distance from the most superior point on the head of the femur to the most inferior point on the distal condyles.
2) Epicondylar breadth of the femur (EBF): The distance between the two most laterally projecting points on the epicondyles.
3) Maximum diameter of the femur head (MDH): The maximum diameter of the femur head measured on the border of the articular surface.
4) Sagittal subtrochanteric diameter of the femur (APS): The anterio-posterior diameter of the proximal end of the diaphysis measured perpendicular to the transverse diameter
5) Transverse subtrochanteric diameter of the femur (TS): The transverse diameter of the proximal portion of the diaphysis at the point of its greatest lateral expansion below the base of the lesser trochanter.

6) Sagittal diameter of the femur at midshaft (APM): The anterio-posterior diameter measured approximately at the midpoint of the diaphysis at the highest elevation of the linea aspera.
7) Transverse diameter of the femur at midshaft (TM): The distance between the medial and lateral margins of the femur from one another measured perpendicular to and at the same level as the sagittal diameter.

Two multivariate statistical procedures were utilized in this analysis. The first is discriminant function analysis with the variable sex being the classification factor. The procedure was calculated with the STATGRAPHICS 4.0. statistical package. This program supplies significance levels for the functions derived, standardized discriminant function coefficients, unstandardized discriminant function coefficients, group statistics, group correlations and classification results. The procedure does not, however, provide the correlations (over the total sample) between the original variable values and the discriminant scores for the derived functions. These coefficients, sometimes identified as "structure coefficients" (Cooley and Lohnes 1971), are interpretable as a variables contribution to the discriminant function score independent of that variable's relationship to the other variables and are useful in cases in which some of the variables analyzed in the procedure are highly correlated with other variables in the function. For this reason a second multivariate procedure, principal components analysis, was also performed. This procedure calculates component weights for each variable in all components. Assuming that the greatest variability in the analyzed sample will be the result of sexual dimorphism, and not for instance the result of temporal trends, the calculated component weights will reflect the contribution that each variable has in differentiating between the sexes.

Results

Multivariate analysis

Table 2 presents the simple descriptive statistics for the data. Significant sexual dimorphism is visible in all variables. Table 3 presents the within-group correlation matrix. Strong, positive correlations are present between the maximum length of the femur and epicondylar breadth (0.590) and maximum diameter of the femur head (0.574). Strong positive correlations are also present between the sagittal subtrochanteric diameter and the sagittal diameter of the femur at midshaft (0.729), and between the transverse subtrochanteric diameter and the transverse diameter of the femur at midshaft (0.749).

The STATGRAPHICS discriminant function procedure calculated one statistically significant discriminant function (Table 4). Standardized and unstandardized discriminant function coefficients are presented in Tables 5 and 6. Group centroids for males and females are shown in Table 7. The unstandardized coefficients (Table 6) are used for calculating discriminant function scores from the raw data. They are presented to readers interested in applying these functions to unknown remains. The measured values of the analyzed variables are simply multiplied with the relevant coefficients for each variable after which the constant is added to the score. All values higher than zero indicate males while all values less than zero indicate females.

Variable		Male		Female	
MLF	mean, (SD)	456.1	(23.5)	412.1	(19.2)
EBF	mean, (SD)	82.5	(4.1)	72.8	(3.8)
MDH	mean, (SD)	48.4	(2.5)	42.0	(2.3)
APS	mean, (SD)	26.0	(2.0)	22.1	(1.7)
TS	mean, (SD)	33.1	(2.6)	29.8	(2.3)
APM	mean, (SD)	28.9	(2.1)	24.9	(2.2)
TM	mean, (SD)	28.6	(2.4)	25.6	(1.9)

Table 2: Means and standard deviations for the seven variables used in the discriminant function analysis.

Variable	MLF	EBF	MDH	APS	TS	APM	TM
MLF	1.000	0.590	0.574	0.450	0.398	0.570	0.373
EBF	0.590	1.000	0.610	0.417	0.374	0.477	0.392
MDH	0.574	0.610	1.000	0.513	0.555	0.424	0.576
APS	0.450	0.417	0.513	1.000	0.438	0.729	0.570
TS	0.398	0.374	0.555	0.438	1.000	0.398	0.749
APM	0.570	0.477	0.424	0.729	0.398	1.000	0.460
TM	0.373	0.392	0.576	0.570	0.749	0.460	1.000

Table 3. The within-group correlation matrix for the analyzed variables.

Discriminant function	Eigenvalue	Canonical correlation	Wilks Lambda	Chi-Square	DF	Significance level
1	2.22609	0.83068	0.3099	180,961	7	0.00000

Table 4. Eigenvalue, cannonical correlation, Wilks Lambda and significance level for the derived discriminant function.

Variable	St. Coeff.
MLF	0.0974
EBF	0.3745
MDH	0.5769
APS	0.3232
TS	-0.1413
APM	-0.0566
TM	-0.0428

Table 5. Standardized discriminant function coefficients.

Variable	Un. Coeff.
MLF	0.0045
EBF	0.0942
MDH	0.2411
APS	0.1736
TS	-0.0576
APM	-0.0246
TM	-0.0216
Constant	-21.312

Table 6. Unstandardized discriminant function coefficients.

Sex	Group centroid
Male	1.482
Female	-1.482

Table 7. Group centroids for males and females.

The derived discriminant function achieved a high degree of accuracy (Table 8). Both males and females were accurately sexed in 93.7% of all cases.

Because of the strong correlations between some of the variables (see Table 3), a second multivariate procedure, principal components analysis, was also performed. Principal components analysis reduces the number of variables in a data set by finding linear combinations of those variables that explain most of the variability in the sample. The procedure calculates component weights for each variable which reflect the contribution of this variable in the linear combination that forms the principal component.

Actual group	Predicted group		
	Male	Female	Total
Male	93.75 %	6.25 %	100.00 %
Female	6.25 %	93.75 %	100.00 %

Table 8. Classification results; percentage of cases correctly predicted for each group.

The principal components analysis produced seven principal components (Table 9), the first two of which explain 85 % of the variability in the sample. Component weights for the first two principal components are presented in Table 10.

Component number	Percent of variance	Cumulative percentage
1	77.2943	77.2943
2	8.3669	85.6613
3	5.5385	91.1999
4	3.1952	94.3951
5	2.2461	96.6412
6	1.9538	98.5951
7	1.4049	100.000

Table 9. Principal components analysis of male and female femora.

Variable	Weights on 1. component	Weights on 2. component
MLF	0.3787	-0.3464
EBF	0.3812	-0.2980
MDH	0.3962	-0.0504
APS	0.3867	-0.1247
TS	0.3525	0.6489
APM	0.3755	-0.2899
TM	0.3732	0.5176

Table 10. Component weights for the first two principal components.

Univariate analysis

While multivariate analysis of all seven variables produces an accuracy of classification of 93.75 %, some variables, by themselves, posses enough sexual dimorphism to be almost as useful in sex determination. This is of great value as it allows sex determination of fragmentary remains.

The variable most useful for univariate determination of sex is the maximum diameter of the femoral head (MDH). Discriminant function analysis using just this one variable shows an accuracy of classification of 91 %. Figure 1 illustrates the frequency distribution of the maximum diameter of the femoral head in relation to the sex of each individual. Following Black (1978) and DiBennardo and Taylor (1979), the midpoint between the male and female mean values was used as a cut-off point for the assignment of sex. As Figure 1 shows, 45.2 mm is the cut-off point between male and female femora. Only 7 out of 80 males and 7 out of 80 females show inconsistency between sex determination based on morphological, pelvic/cranial criteria, and sex determination based on the maximum diameter of the femoral head.

Very good results have also been achieved by using only the variable epicondylar breadth of the femur (EBF). Discriminant function analysis using only this variable achieved an accuracy of prediction of 87.5 % with the cut-off point between males and females at 77.7 mm. All individuals with epicondylar breadths larger than this value are classified as males, those with lower values as females.

Slightly less good, but also useful results have been achieved with the variable maximum length of the femur (MLF). Discriminant function analysis using only this variable gives an accuracy of 85 % with the cut-off point between males and females at 434.0 mm. All individuals whose femoral length is greater than this are classified as males, those with femoral lengths lower than this as females.

Discussion

Discriminant function analysis has two broad objectives: 1) *classification* - to assign individuals to groups on the basis of shared similarities; and 2) *analysis* - to delineate the dimensions along which the groups are maximally differentiated.

Accuracy of classification

Classification is based on comparison of an individual's profile with the average profiles of the two groups, one of which into he must be assigned.

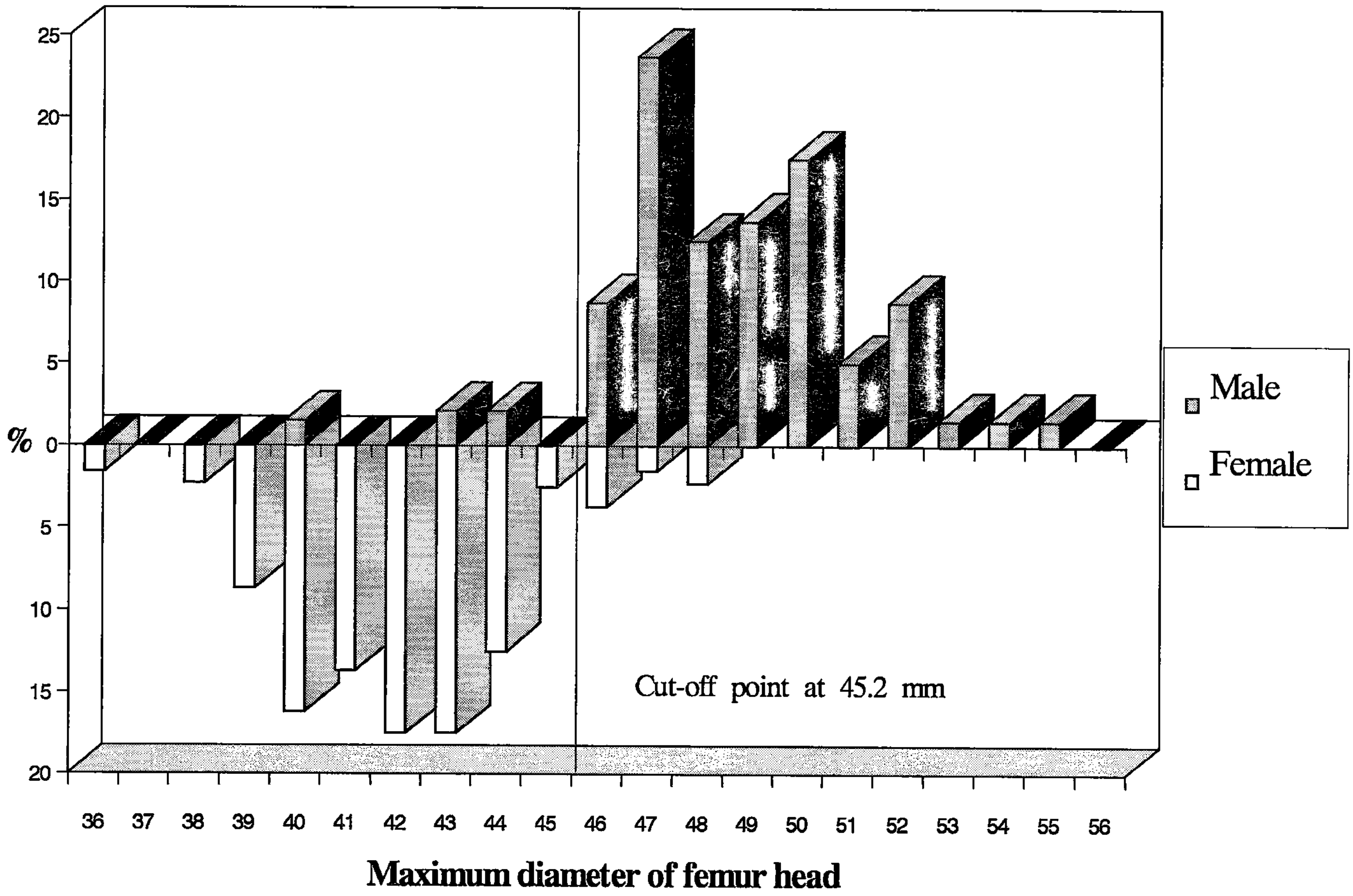

Figure 1. Distribution of the maximum diameter of the femoral head (MDH) in relation to sex. Individuals to the right of the cut-off point are classified as male and those to the left as female.

The accuracy of prediction achieved with the present discriminant function analysis is surprisingly good. MacLaughlin and Bruce (1985) report of an overall accuracy for sexing of 90.6 % based on one variable, maximum antero-posterior diameter of the femoral shaft in the homogeneous prehistoric Scottish Short cist population. A comparable rate of accuracy of 90 % was achieved by Iscan and Miller-Shaivitz (1984a) in the Black and White North American Haman-Todd skeletal population of known age and sex. DiBennardo and Taylor (1979) report of an overall accuracy for sexing of 82 % in their study of a White North American population of verified age an sex. DiBennardo and Taylor (1982) also analyzed a Black North American population of known age and sex and achieved an overall accuracy of 76.4%. Black (1978) achieved a 86.7 % overall accuracy with discriminant function analysis of a homogeneous North American Indian population of unverified age and sex with the use of one variable, femoral midshaft circumference.

It is clear, then, that a 93.75 % accuracy, achieved with all seven variables represents a high accuracy for discriminant function sexing. Furthermore, the accuracy achieved with only one variable, maximum diameter of the femoral head, is also very high (91 %), comparable to the overall accuracy achieved by MacLaughlin and Bruce (1985), and slightly better than that achieved by Black (1979). This accuracy also compares favorably with more complex means of sexing. Giles and Elliot (1963) reported a range of from 81 % to 89 % accuracy for discriminant functions using from four to eight cranial measurements, Giles (1964) achieved 82 % to 85 % accuracy in sexing the mandible using discriminant functions based on from three to six measurements, and Ditch and Rose (1972) sexed prehistoric dentition with from 88 % to 95 % accuracy using combinations of from three to five dental measurements.

Functional interpretation

Based on the standardized discriminant function coefficients two components can be identified in the sexing function. These components can be described as a general size factor, based on high positive loadings for maximum diameter of femoral head (MDH), epicondylar breadth (EBF) and maximum length (MLF), and a shape component based on negative loadings for transverse subtrochnateric diameter (TS), sagittal diameter at midshaft (APM) and transverse diameter at midshaft (TM), see Table 5.

The size factor can further be divided into two components: joint size, which based on the high loadings for maximum diameter of the femur head and epicondylar breadth seems to contribute more, and maximum length of the femur, which seems to be less important.

The presence of a general size factor is also evident in the component weights for the first principal component (Table 10), all of which show positive loadings indicating that the size difference between male and female femora is of major significance in discriminant function analysis of the femur.

The shape component is identified on the basis of negative loadings for subtrochanteric transverse diameter (TS), and sagittal (APM) and transverse (TM) diameter at midshaft (see Table 5) which indicate that females have smaller transverse subtrochanteric diameters and smaller sagittal and transverse midshaft diameters than males. This difference is also confirmed by the component weights on the second principal component (Table 10) which show an inverse relationship between transverse subtrochanteric diameter and transverse sagittal diameter and all of the other analyzed variables indicating that female femora differ from male by having smaller transverse diameters.

This functional interpretation of differences in male and female femora is similar to that of DiBennardo and Taylor (1982) and relies on the premise that size (diaphysis length and joint size) is largely determined by intrinsic factors while femoral midshaft sagittal and transverse diameters are largely dependent on the functional demands of weightbearing and muscle activity. The primary basis of sexual dimorphism in the femur therefore appears to be size, particularly joint size, in combination with commensurable body weight.

Application and limitations

This discriminant function was developed to help sex medieval archaeological populations from continental Croatia. As already stated, discriminant functions are population specific and formulae developed on one sample cannot be used on others (Birkby 1966; Kajanoja 1966). The multivariate and univariate discriminant functions presented here seem, however, also to be able to accurately predict sex in Late Antique populations from continental Croatia as well as in Late Antique and medieval populations from Dalmatia.

The discriminant functions developed here were tested on two populations from continental Croatia: the medieval population from Đakovo which is dated to the period between the 11th and 16th century (Filipec 1996;189) and on the Late Antique population from Štrbinci which is dated to the second half of the 4th century (Gregl 1994; Migotti 1997: 219), and on two populations from Dalmatia: the medieval population from Danilo dated to the period from the 10th to the 16th century (Šmalcelj personal communication), and the Late Antique population from the site of Ad Basilicas Pictas in Split dated to the period from the 5th to the 6th century (Rizmondo personal communication).

The following results were achieved. In Đakovo the discriminant function was tested on 20 male and 20 female femora. Using all seven variables 19/20 (95 %) of male and 18/20 (90 %) of female femora were accurately sexed. When only one variable, maximum diameter of the femur head (MDH), was used 18/20 (90 %) of male and 18/20 (90 %) of female femora were correctly sexed.

Only 4 male and 2 (fragmentary) female femora were available for analysis in Štrbinci. All six femora were correctly sexed based on the cut-off point of 45.2 mm for the diameter of the femoral head.

In Danilo the discriminant function was tested on 15 male and 10 female femora. Using all seven variables 14/15 (93 %) of male and 9/10 (90 %) of female femora were accurately sexed. Using only the diameter of the femoral head 13/15 (87 %) of male and 9/10 (90 %) of female femora were correctly sexed.

Eight male and one female femur were available for analysis in Split. Using all seven variables all of the male 8/8 (100 %) and the one available female femur 1/1 (100 %) were accurately sexed. When only the maximum diameter of the femur head was utilized 7/8 (87 %) of the male femora were correctly sexed as well as the one available female femur.

Conclusion

The results of this investigation indicate that femoral measurements are a useful tool in the determination of sex, especially in cases when the skeletal remains are fragmentary or poorly preserved. For skeletal collections in good condition, discriminant function analysis of seven femoral measurements provides an accuracy of sex determination in 93.7 % of all cases. In poorly preserved or fragmented skeletal collections univariate analysis of the maximum diameter of the femoral head provides an accuracy of 91 %, analysis of the epicondylar breadth of the femur provides an accuracy of 87.5 %, and analysis of the maximum length of the femur provides an accuracy of 85 %. At present it appears that the discriminant function formulae can be applied not only to medieval but also to Late Antique populations from continental Croatia and Dalmatia. Further testing is, however, necessary to confirm this assumption and to determine if the formulae are applicable to other time periods.

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ABBREVIATIONS:

AJPA	- American Journal of Physical Anthropology
AP	- Arheološki Pregled, Beograd
Opusc. Archaeol.	- Opuscula Archaeologica; Radovi Arheološkog zavoda Filozofskog fakulteta u Zagrebu.

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SAŽETAK

DISKRIMINANTNO FUNKCIJSKO ODREĐIVANJE SPOLA KOD ČITAVIH I FRAGMENTIRANIH FEMURA SA SREDNJOVJEKOVNIH LOKALITETA IZ KONTINENTALNE HRVATSKE

Ključne riječi: Diskriminantne funkcije, određivanje spola, femur, srednji vijek, Hrvatska

Na temelju uzorka od 160 femura (80 muških i 80 ženskih) sa četiri srednjovjekovna lokaliteta u kontinentalnoj Hrvatskoj: Nove Rače, Stenjevca, Privlake i Starih Jankovaca, izračunate su diskriminantno funkcijske jednadžbe za određivanje spola. Jednadžbe su izračunate na temelju sljedećih varijabli: 1) maksimalne duljine femura - udaljenosti od najsuperiornije točke glave femura do najdistalnije točke na distalnim kondilima, 2) epikondilarne širine - udaljenosti između dviju najlateralnijih točaka na epikondilima, 3) maksimalnog promjera glave femura - najvećeg promjera na glavi femura, 4) sagitalnog subtrohanteričnog promjera - anteroposteriorni promjer proksimalne dijafize femura izmjeren okomito na transverzalni promjer, 5) transverzalnog subtrohanteričnog promjera - transverzalni promjer proksimalne dijafize femura izmjeren na mjestu najveće lateralne ekspanzije dijafize ispod malog trohantera, 6) sagitalnog promjera na sredini dijafize - anteroposteriorni promjer na sredini dijafize femura i 7) transverzalnog promjera na sredini dijafize - transverzalni promjer na sredini dijafize femura.

Uz upotrebu svih sedam varijabli diskriminantno funkcijska jednadžba polučila je uspješnost od 93,75 % (samo su 5 od 80 muških i 5 od 80 ženskih femura bili pogrešno klasificirani). Kako je na arheološkim lokalitetima ljudski osteološki materijal vrlo često fragmentiran ili loše uščuvan, izračunate su i diskriminantne funkcije koje se koriste samo jednom varijablom. Najkorisnija se pri tome pokazala varijabla najvećeg promjera glave femura na temelju čije se dimenzije spol može utvrditi s 91 % točnosti. Diskriminantno funkcijska analiza pokazala je da je granična vrijednost za određivanje spola na temelju veličine glave femura 45,2 mm. Sve vrijednosti iznad ove granice označavaju muškarca dok sve vrijednosti ispod označavaju ženu. Visoka točnost od 87,5 % postignuta je i s varijablom epikondilarna širina. Granična vrijednost za određivanje spola na temelju ove varijable je 77,7 mm - sve vrijednosti iznad ove granice označavaju muškarca, a sve vrijednosti ispod ženu. Slična točnost od 85 % postignuta je i s varijablom najveća duljina femura kod koje je granična vrijednost za određivanje spola 434,0 mm - vrijednosti iznad označavaju muškarca, a vrijednosti ispod ženu.

Analiza polučene diskriminantne funkcije pokazuje da ona sadrži dvije komponente. Prva komponenta određena je veličinom kosti, poglavito veličinom zglobnih ploština, dok je druga komponenta definirana oblikom kosti u subtrohanteričnom području i na sredini dijafize.

Dobivena diskriminantna funkcija dodatno je testirana na drugim srednjovjekovnim i kasnoantičkim populacijama iz Hrvatske. Analizirane su kasnoantičke populacije iz Štrbinaca kraj Đakova i s lokaliteta Ad Basilicas Pictas u Splitu i srednjovjekovne populacije iz Đakova i Danila Gornjeg kraj Šibenika. Primjena diskriminantno funkcijskih jednadžbi na ovim populacijama dala je točnost određivanja spola u rasponu od 87 % do 95 %.