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Sex diagnosis of the Early Medieval population of Great Moravia (9^{th} to 10^{th} century): proposed population specific discriminant functions for cranial measurements.

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Abstract. **This study aimed to analyse sexual dimorphism in, and to produce a practical discriminant functions for determining the sex of early medieval Slavonic crania from the territory of the Great Moravian Empire (9^{th} to 10^{th} century). In total, adult skeletons of three cemeteries from were utilised only (Mikulčice II and Kostelisko as reference sample and Prušánky I as the target sample). Discriminant functions were developed using the principle of primary and secondary sex diagnosis. All individuals (n=210) were sexed using reliable methods of the pelvis (primary sex diagnosis) with posterior probability 0.95 for sex allocation. A total of 12 cranial measurements were taken from 98 males and 61 females skeleton. These were subjected to Statistica 7.1 discriminant function analysis. The proposed 9 population-specific discriminant functions with average accuracy from 80 % t o 86 % are suitable for determining the sex of early medieval skeletons from the Great Moravian region.**

■ **Great Moravian population, Mikulčice, Prušánky, Primary Sex Diagnosis, Secondary Sex Diagnosis, Discriminant functions**

INTRODUCTION

The direct use of measurements taken from the skeleton or simple methods such as indexes (Sullivan & Hall 1981) does not guarantee reliable sex diagnosis (Bruzek 1991). Thus the only objective tool for determining the sex of skeletal remains is discriminant function analysis (DFA), although discriminant functions proposed for the skull, mandible and long limb bones (e.g. Krogman & Iscan 1986, Sjovold 1988), are population specific. This fact has been pointed out by a number of researchers (e.g. Henke 1977, Novotný 1981), who maintain that discriminant functions only apply to the population for which they were proposed or calculated. In order to correct for different conditions of use, these authors propose modifying the discriminant function's sectioning point, however this requires the availability of a sufficient number of skeletons (bones) of known sex from the new population. This seemingly paradoxical condition appears totally unusable for archaeology, i.e. for past populations. The pitfall for users of discriminant functions, represented by the size or format of measurements, is the source of significant inaccuracy, interpretative errors and conflicting results (Bruzek & Murail 2006).

All morphological methods used for sex determination reflect the sexual dimorphism of the skeleton. The degree of this dimorphism is a limiting factor for successful sex determination. For these reasons, methods proposed for determining sex according to the skeleton are not, and cannot be absolutely successful. There is a generally accepted view that a single characteristic cannot lead to a reliable result. The success of morphological methods for determining sex is estimated at 80 percent or more; however the reliability of these results is somewhat lower. However the demand for accuracy and reliability today must be higher and the arbitrarily set limit of 95% is a necessity in forensic anthropology (Scheuer 2002) and a need in anthropology studying past populations (Bruzek & Murail 2006). A high degree of inaccurate sex diagnosis has a significant affect on archaeological, taxonomic and biological interpretations and in such cases we must look for other explanations for methodological errors (Bruzek 1996). Sexual dimorphism in body size is variable, difficult to gauge and is often a random phenomenon, being sensitive to changes in living conditions, as well as genetic changes in the population. These factors are then necessarily reflected in the morphometric characteristics of the human skeleton.

The basis for correct and reliable sex determination is primary and secondary sex diagnosis (Murail et al. 1999) which was successfully tested on an archaeological population of known sex from Spitalfield (Molleson & Cox 1993). This method consists of three stages. In the first stage we determine the primary sex diagnosis of individuals on the basis of the pelvic bone, in those cases where the pelvic bone has been preserved. We can exploit the fact that reliable methods based on pelvic characteristics are not population specific (e.g. Brůžek 2002). In the second stage, we calculate DFA and posterior probability based on extra-pelvic measurements in the group of individuals whose sex was determined in the first stage. The specific DFA thus acquired are used to determine the sex of those individuals whose pelvic bone were not preserved or whose sex could not be determined. Proposed population specific discriminant functions for various parts of the skeleton, where the sex of skeletal remains was determined in the primary stage using the pelvis, have been used in numerous studies (e.g. Dittrick & Suchey 1986, Murail 1996, Wrobel et al. 2002, Bocquentin 2003, Stojanowski 2003). Although the calculation of discriminant functions is now simpler thanks to computer technology and software for the calculation of discriminant functions, this step must still be preceded by primary sex diagnosis based on the pelvis, which is not always possible in practice.

The aim of this contribution is to offer a suitable tool for determining the sex of not only solitary human skeleton finds, but also of extensive burial sites, prior to detailed laboratory processing. The proposed discriminant functions for skull measurements are only applicable for Central European populations of the 9th to 12th century. This contribution only looks at the skull, which is often the part of the skeleton most closely examined by field workers. This method thus aims to contribute to the relatively quick and reliable determination of the sex of adult individuals. The chosen approach can be applied to other parts of the skeleton, which will be the subject of further contributions.

MATERIAL AND METHODS

MATERIAL: The skeletal remains from three Great Moravian burial sites were used for this study. Two of the burial sites are part of the Mikulčice-Valy agglomeration settlement – this being the second burial site at the three nave basilica on the grounds of the castle with 569 graves (Stloukal 1967) and the burial site at Kostelisko beneath Mikulčice Castle with 425 graves (Velemínský 2000, Velemínský et al. 2005). The third burial site – Prušánky

I – in the Mikulčice centre hinterland provided approximately 330 graves (unpublished data). All the burial sites date to the 9-10th century. Only 216 adult individuals from the Mikulčice-Valy burial site and 116 adult individuals from the Kostelisko burial site could be used for sex determination. A criterion for selection was the preservation of the pelvic bone or a part thereof. A small sample (n = 28) of adult individuals from the Prušánky I burial site with preserved pelvic bones and skulls were used as a reliability test of the proposed discriminant functions. The studied material is deposited in the Department of Anthropology, National Museum, Praha.

Methods: (1) Primary sex diagnosis is based on the primary sex diagnosis (PSD) program (Murail et al. 2005). This involves the calculation of posterior probability for an unknown pelvic bone, which classifies it as either male or female according to the chosen level of significance. The database contains more than 2,000 pelvic bones for individuals of known sex from various populations on four continents, dating from the 18th to 20th century. Sex is determined by comparing the specimen's measurements to the database and computing the probability it is a female or a male from any combination of four variables among ten. The following pelvic measurements were taken from the pelvic bones (Tab.1). Sex was allocated using the PSD program only if posterior probability was equal to, or higher, than 0.95.

Table 1. List of pelvic variables. The measurements selected for the probabilistic sex diagnosis (DSP) after Murail et al. (2005). Lettre M refers to Martin measurements' codes (Bräuer 1988).

Variables	Description	Reference
PUM (M14)	Acetabulo-symphyseal pubic length	Bräuer 1988
SPU	Cotylo-pubic breadth	Gaillard 1960
DCOX (M1)	Pelvic length	Bräuer 1988
IIMT(M15.1)	Greater sciatic notch height	Bräuer 1988
ISMM	Ischium post-acetabular length	Schulter-Ellis et al. 1983
SCOX (M12)	Iliac breadth	Bräuer 1988
SS	Spino-sciatic length	Gaillard 1960
SA	Spino-auricular length	Gaillard 1960
SIS (M14.1)	Cotylo-sciatic breadth	Bräuer 1988
VEAC (M22)	Vertical acetabular diameter	Bräuer 1988

(2) The secondary sex diagnosis of skulls uses 12 linear measurements according to Martin (Bräuer 1988) and Howells (1996) as presented in Tab. 2 (see Fig. 1).

Selection of discriminant functions: The selection of measurements for the calculation of discriminant functions was subject to three criteria: (a) measurements that have proven to be successful by other authors in discriminant analyses (Hanihara 1959, Giles & Elliot 1963, Kajanoja 1966, Henke 1974, Šefčáková et al. 1999, Franklin 2005), (b) a list of standard cranial measurements taken by the Anthropological Department of the National Museum in Prague, (c) good condition of skeletal remains to be processed.

The calculation of discriminant functions and other statistics was carried out using Statistics 7.1. and MS Excel 2003 software. The group of specimens from the Mikulčice burial sites was used to propose discriminant functions for the skull and those from the Prušánky burial site were used as a test sample to verify their validity.

Fig. 1. Cranial measurements and anthropological points. a) frontal position, b) lateral position c) basal position.

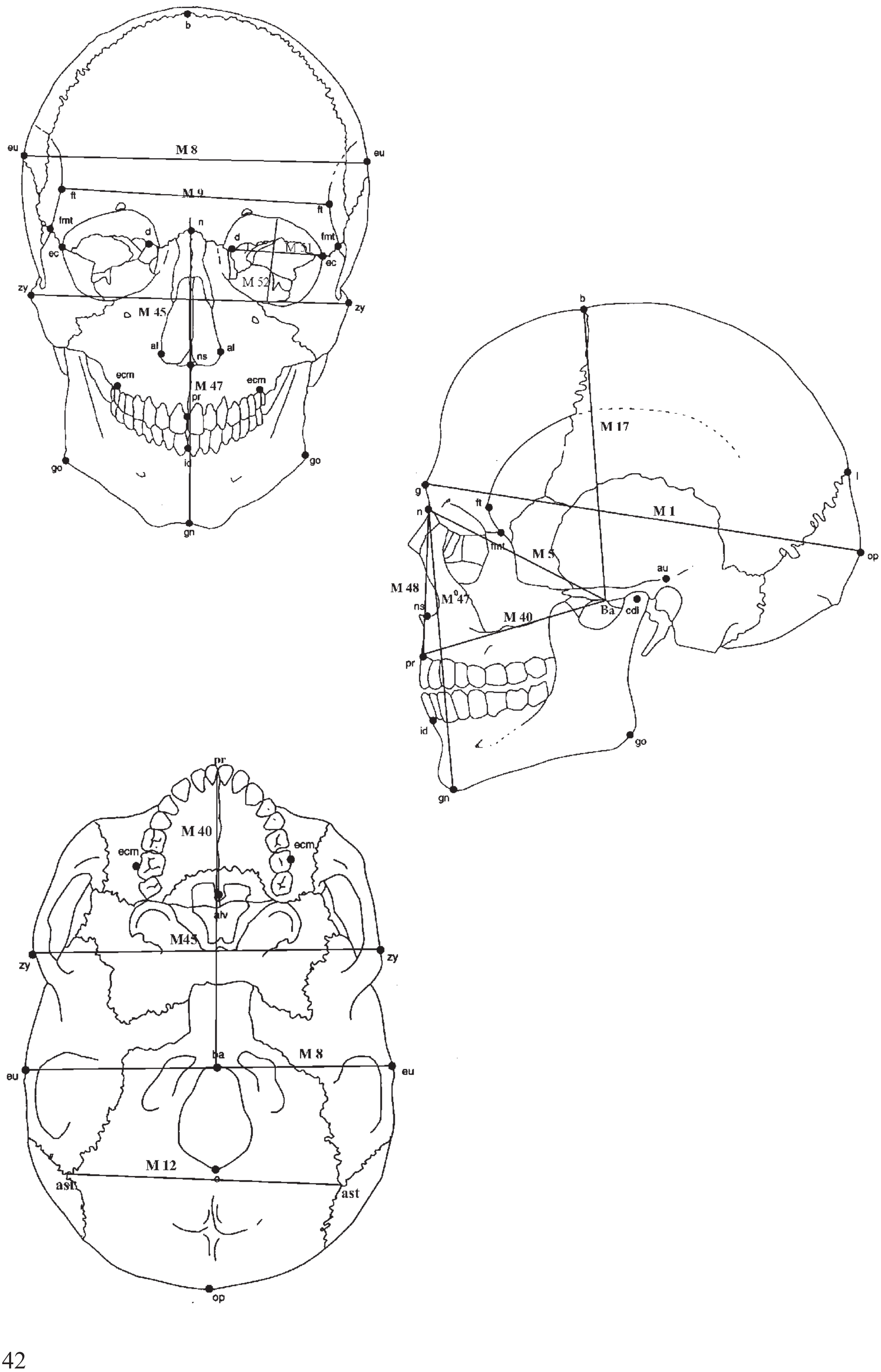


Table 2. Linear measurements used for secondary sex diagnosis. Explanatory text: Ab. = Abbreviation of measurements after Martin (Bräuer 1988), in parantheses after Howells (1996); CAP = cranial anthropological points.

Ab.	Measurements	CAP	Definition
M1 (GOL)	Maximum cranial length	g-op	The distance of glabella (g) from opisthocranion (op) in the mid sagittal plane measured in a straight line
M5 (BNL)	Cranial base length	ba-n	The direct distance from nasion (n) to basion (ba)
M8 (XCB)	Maximum cranial breadth	eu-eu	The maximum width of the skull perpendicular to the mid sagittal plane wherever it is located with the exception of the inferior temporal line and the immediate area surround the latter (i.e. the posterior roots of the zygomatic arches)
M9 (WFB)	Minimum frontal breadth	ft-ft	The direct distance between the two frontotemporale
M12 (ASB)	Maximum occipital breadth	ast-ast	the direct distance between the two asterion
M17 (BBH)	Basion bregma height	ba-b	The direct distance from the lowest point on the anterior margin of the foramen magnum, basion (ba), to bregma
M40 (BPL)	Basion prosthion length	ba-pr	The direct distance from basion (ba) to prosthion (pr)
M45 (ZYB)	Bizygomatic breadth	zy-zy	The direct distance between each zygion (zy), located at the most lateral points of the zygomatic arches
M47 (-)	Facial height	n-gn	The direct distance from nasion (n) to gnathion (gn)
M48 (UFHT)	Upper facial height	n-pr	The direct distance from nasion (n) to prosthion (pr)
M51 (OBB)	Orbital breadth	d-ec	The laterally sloping distance from dacryon (d) to ectoconchion (ec)
M52 (OBH)	Orbital height		The direct distance between the superior and inferior orbital margins

RESULTS

Given the good condition of pelvic bones (Tab.3), primary sex diagnosis (PSD) was carried out on 197 skeletons from the second Mikulčice-Valy burial site, of which sex was determined for 162 individuals. Of the 68 skeletons with pelvic bones from the Kostelisko burial site, sex was determined for 48 individuals. Sex was thus determined with a probability of 95% or higher for a total of 210 individuals from Mikulčice based on pelvic bones. Skeletons with reliable sex diagnosis based on pelvic bones will be used in secondary sex diagnosis to calculate discriminant analyses based on the skull. The testing sample from Prušánky allowed the sex determination of skull from 28 individuals determined by primary sex diagnosis.

Table 3 Results of primary sex diagnosis (PSD) of specimens from the Great Moravian burial sites in Mikulčice based on the pelvis

	Inapplicable	M	F	M & F	?	Total
Mikulčice - castle n = 216 (100 %)	19 (8.8%)	106 (49.1 %)	56 (25.9 %)	162 (75 %)	35 (16.2 %)	197 (91.2 %)
Mikulčice - subcastle n = 116 (100 %)	48 (41.4 %)	22 (19 %)	26 (22.4 %)	48 (41.4 %)	20 (17.2 %)	68 (58.6 %)
Mikulčice - total n = 332 (100 %)	67 (20.2 %)	128 (38.6 %)	82 (24.7 %)	210 (62.3 %)	55 (16.6 %)	265 (79.8 %)

Secondary sex diagnosis was carried out on specimens from both Mikulčice burial sites, that is, on individuals whose sex had been determined by PSD and from which we could take cranial measurements. We thus had 98 skulls belonging to males and 61 skulls belonging to females for the proposal of discriminant functions. This number is somewhat lower than the number of individuals whose sex was determined using the pelvis, as the skulls of a certain number of individuals had not preserved.

The basis for the calculation of discriminant functions is 12 cranial measurements, whose basic statistics are given in Table 4. There were significant sex differences in all of the measurements studied in the skulls from Mikulčice (Tab. 4). The average value of measurements is significantly higher for men than for women.

Tab 4. Summary statistics of cranial variables in the Greath Moravia skeletal sample employed in seonary sex diagnosis (discriminant function analyses). M = abbreviation of measurements after Martin (Bräuer, 1988); p = probability level ; * = 0,05 (value >1,960), ** = 0,01 (value > 2,576), * = 0,001 (value > 3,290)**

	MALES					FEMALES						
	n1	$\bar{x}$	**Min**	**Max**	**s**	**n2**	$\bar{x}$	**Min**	**Max**	**s**	**t-test**	**p**
M1	91	187,9	171	204	6,5	54	179,6	165	193	6,0	8,260	***
M5	80	104,3	91	116	4,7	48	97,5	90	110	3,6	6,758	***
M5	88	142,0	130	155	5,3	54	138,5	128	150	5,2	3,838	***
M9	93	99,9	88	126	5,1	59	96,1	88	103	3,7	3,775	***
M12	82	111,4	100	122	5,2	47	108,4	98	124	5,0	2,995	**
M17	86	137,7	126	160	5,5	52	131,3	122	143	4,5	6,483	***
M40	74	99,0	84	113	5,7	47	93,4	82	105	5,1	5,580	***
M45	72	133,6	101	144	5,8	47	125,5	104	136	6,1	7,817	***
M47	79	120,8	105	136	7,0	49	111,6	98	123	6,4	9,236	***
M48	81	72,6	63	82	12,7	51	67,5	58	77	4,1	6,337	***
M51	81	43,7	37	105	9,7	49	40,5	36	44	2,2	3,202	**
M52	81	35,4	22	102	10,9	49	32,9	28	37	2,0	2,522	*

We calculated 9 discriminant function analyses (DFA), which are summarised in Table 5. Eight DFA are classic linear discriminant function analyses, the ninth is a forward stepwise discriminant function analysis. The selection of measurements was based on measurements commonly used to determine sex on the basis of the skull. The number was optimised to take the condition of the skeletal material into account. The first DFA includes 4 measurements, of which two describe the neurocranium and two the face. The second DFA combines 3 measurements of the neurocranium with two measurements of the face. The third DFA is a modification of the second DFA with 3 measurements of the neurocranium and the width of the face, while the fourth DFA only uses three cranial measurements. The fifth DFA uses 4 measurements, 2 of the neurocranium and 2 of the face. The sixth and seventh DFA only uses neurocranial measurements. The eighth DFA once again combines measurements of the face and neurocranium. The final, stepwise DFA chose 5 of the total 12 measurements which contributed to the separation of males from females. According to Wilks' lambda statistics values, all DFA are significant. Wilks' statistics have a value from 0 (absolute discrimination between groups) to 1 (no discrimination between groups).

Tab. 5. Summary statistics of discriminant function analyses (DFA) of cranial variables in pooled sample of Greath Moravian cemeteries from Mikulčice. (a) Stepwise DFA of 12 variables, (b) number of variables entered, (M) abbreviation of measurements after Martin (Bräuer 1988).

Discriminant function (DF)	Number of variables	Wilk's λ	F-statistics	Probability	Variables employed
DFA 1	4	0,582	17,930	0,000	M 1, M 40, M 45, M 48
DFA 2	5	0,549	16,266	0,000	M 1, M 5, M 8, M 45, M 48
DFA 3	4	0,562	19,690	0,000	M 1, M 5, M 8, M 45
DFA 4	3	0,556	27,716	0,000	M 1, M 17, M 45
DFA 5	4	0,594	17,562	0,000	M 1, M 8, M 45, M 52
DFA 6	5	0,524	19,784	0,000	M 1, M 5, M 8, M 12, M 17
DFA 7	3	0,621	26,055	0,000	M 1, M 8, M 17
DFA 8	4	0,577	18,858	0,000	M 1, M 8, M 45, M 48
DFA 9 [(a)]	5[(b)]	0,511	16,636	0,000	M 5, M 17, M 45, M 47, M 51

Table 6 shows the sexing accuracy for 9 DFA in the sample of early medieval Slavonic crania. All of the proposed DFA have a sexing accuracy higher than 80%, of which DFA 6 has the highest rate with 86%. However, the risk of error is relatively high and, depending on the each or particular DFA, ranges from 14 to 20%. The calculation of DFA was only possible for approximately two thirds of the starting number of 98 men and 61 women whose sex was determined according to the pelvis, as individuals with incomplete data were removed from the calculation.

The Statistica 7.01 software we used gives two linear equations as the result of DFA for two groups, into which the appropriate values for cranial measurements taken are placed for the case we wish to classify. A higher result for one of the two equations determines the group to which the new case belongs. In order to simplify application, we subtracted two classification functions from each other to obtain at a single, standardised equation. The final DFA are summarised in Table 7. Cranial length (M1) and bizygomatic facial width (M45) are of the greatest significance for determining sex, as the coefficient values of these measurements are highest for individual DFA. However the proposed DFA can only be used for old Slavonic (Great Moravian) populations of the early medieval period in Central Europe. We compare the result of the linear equation (DFA) for the unknown case with the male-female sectioning point, which in the case of a standardised equation equals 0, as the value of the centroid for men and women is the same. A positive value indicates a female sex and a negative value, a male sex. Values in the interval near zero must be considered as indeterminate cases, independently from the assigned sex by the discriminant function.

Tab. 6. Secondary sex diagnosis: sexing accuracy for discriminant function 1–9 for the pooled sample of Great Moravia skulls (Mikulčice-Valy a Mikulčice-Kostelisko Cemeteries). (a) stepwise DFA of 12 variables, (b) variables entered, (c) M1, M 8, M 9, M 12, M 40, M48, M 52 - variables that did not enter, N = ratio of sexes correctly identified to the total of thet sex examined in a given DFA, M = symbol of measurements after Martin (Bräuer 1988).

DISCRIMINANT FUNCTION (DF) N°	NUMBER OF VARIABLES	VARIABLES	MALES		FEMALES		CORRECTLY ASSIGNED	
			N	%	N	%	N	%
DFA 1	4	M, M 40, M 45, M 48	55/65	84,6	32/40	80,0	85/105	82,9
DFA 2	5	M 1, M 5, M 8, M 45, M 48	54/65	83,1	32/40	80,0	86/105	81,9
DFA 3	4	M 1, M 5, M 8, M 48	55/66	83,3	32/40	80,0	87/106	82,1
DFA 4	3	M 1, M 17, M 45	57/67	85,1	33/41	80,5	90,108	83,3
DFA 5	4	M 1, M 8, M 45, M 52	59/68	86,8	33/40	82,5	92,108	85,2
DFA 6	5	M 1, M 5, M 8, M 12, M 17	63/74	85,1	36/41	87,8	99/115	86,1
DFA 7	3	M 1, M 8, M 17	67/82	81,7	39/50	78,0	106/132	80,3
DFA 8	4	M 1, M 8, M 45, M 48	58/67	86,6	34/41	82,5	92/108	85,2
DFA 9 (a)	5	M 5, M 17, M 45, M 47, M 51 (b)	54/64	84,4	33/40	82,5	87/104	83,7

Tab. 7. Discriminant function analyses of cranial variables in Great Moravia burial- ground samples with classification rules for correct identifying of sex with probability of 50% (correct discrimination)
Key to measurements in Table 2

FUNCTION	EQUATION	CLASSIFICATION	CENTROID
		p = 0,5	
DFA 1	(M1* -0,159) + (M40* -0,044) + (M45* -0,180) + (M48* -0,037) + 59,478	F > 0 > M	2,983
DFA 2	(M1* -0,098) + (M5* -0,196) + (M8* -0,005) + (M45* -0,164) + (M48* -0,034) + 62,209	F > 0 > M	3,417
DFA 3	(M1* -0,088) + (M5* -0,206) + (M8* -0,023) + (M45* -0,158) + 60,607	F > 0 > M	3,256
DFA 4	(M1* -0,123) + (M17* -0,183) + (M45* -0,151) + 66,829	F > 0 > M	3,331
DFA 5	M1* -0,183) + (M8* + 0,001) + (M45* -0,183) + (M52* - 0,046) + 58,784	F > 0 > M	2,270
DFA 6	(M1* - 0,124) + (M5* -0,163) + M8* -0,093) + (M12* +0,111) + (M17* -0,228) + 70,583	F > 0 > M	3,877
DFA 7	(M1* -0,143) + (M8* -0,053) + (M17* -0,184) + 58,446	F > 0 > M	2,555
DFA 8	(M1* -0,186) + (M8* +0,013) + (M45* -0,191) + (M48* - 0,039) + 60,001	F > 0 > M	3,052
DFA 9	(M17* -0,126) + (M47* -0,106) + (M5* -0,197) + (M45* -0,109) + (M51* -0,053) + 65,354	F > 0 > M	4,033

To verify the accuracy of the proposed DFA, we carried out a reliability test on a small sample of 28 skulls (13 ♀♀ and 15 ♂♂) from the Prušánky I burial site, whose sex was determined in advance by PSD. The Prušánky I burial site is located in the Mikulčice centre hinterland and also dates to the Great Moravian period. The results of the test are presented in Table 8. We were able to determine the sex of 15 to 20 individuals using the proposed DFA. It was not possible to apply some of the DFA in eight to thirteen cases,

Tab. 8. Test of the discriminant function analyses of cranial variables in population sample from Prušánky burial-ground (classification rule: p = 0,5). Explanatory text: DFA 1, DFA 2, DFA 3 …….= values of discriminant function analysis 1, 2, 3….., PSD = primary sex diagnosis, SSD = secondary sex diagnosis, M= male, F = female, ?= indetermined sex; * false sex determination in opposite to PSD.

Prusanky N*	Primary sex diagnosis "PSD"	DFA 1 value	DFA 2 value		DFA 3 value		DFA 4 value		DFA 5 value		DFA 6 value		DFA 7 value		DFA 8 value		DFA 9 value			Applicability
		value	sex	value	sex	value	sex	value	sex	value	sex	value	sex	value	sex	value	sex	value	sex	
10	F	–	no	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	0/9
26	F	2,147	F	2,164	F	1,835	F	0,838	F	1,719	F	0,107	F	0,841	F	2,151	F	2,756	F	9/9
58	F	–	no	1,818	F	1,671	F	2,974	F	1,904	F	4,61	F	2,902	F	2,09	F	2,779	F	8/9
61	F	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
62	F	1,903	F	2,044	F	1,703	F	1,662	F	1,449	F	2,03	F	1,59	F	1,787	F	2,858	F	9/9
67	F	1,104	F	0,84	F	0,515	F	0,455	F	0,574	F	1,097	M	0,258	M	0,921	F	1,982	F	9/9
174	F	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
182	F	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
212	F	2,316	F	2,155	F	1,63	F	2,513	F	1,814	F	2,37	F	2,195	F	2,351	F	3,908	F	9/9
214	F	–	no	0,98	F	0,801	F	2,244	F	0,49	F	3,362	F	2,486	F	0,673	F	2,739	F	8/9
25	F	0,699	F	1,269	F	0,864	F	0,738	F	0,371	M	0,726	F	0,096	M	0,217	F	4,665	F	9/9
252	F	–	no	–	no	–	non	–	non	2,743	M	–	non	–	non	2,408	M	–	non	2/9
283	F	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
18	M	1,13	M	1,401	M	1,28	M	1,935	M	0,977	M	2,277	M	1,198	M	1,142	M	2,502	M	9/9
22	M	1,088	M	0,25	M	0,397	M	1,488	M	1,513	M	1,341	M	2,009	M	1,36	M	0,065	M	9/9
34	M	4,901	M	4,085	M	4,146	M	5,629	M	4,806	M	4,953	M	4,862	M	4,784	M	3,456	M	9/9
50	M	0,293	M	0,387	M	0,288	M	0,715	M	0,016	M	0,229	M	0,217	M	0,202	M	1,247	M	9/9
64	M	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
65	M	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
75	M	1,648	M	2,132	M	2,113	M	1,512	M	1,66	M	2,127	M	1,009	M	1,769	M	2,001	M	9/9
84	M	–	no	–	no	–	non	–	non	0,354	F	–	non	–	non	0,446	F	–	non	2/9
129	M	0,532	M	0,727	M	0,922	M	1,506	M	0,555	M	1,961	M	1,258	M	0,484	M	1,505	M	9/9
138	M	3,278	M	3,798	M	3,489	M	1,912	M	2,944	M	2,202	M	1,25	M	3,189	M	3,706	M	9/9
154	M	–	no	–	no	–	non	–	non	–	non	–	non	–	non	–	non	–	non	0/9
178	M	1,093	M	1,199	M	1,21	M	0,809	M	1,069	M	0,811	M	0,237	M	0,981	M	0,259	M	9/9
189	M	–	no	–	no	–	non	–	non	0,083	F	–	non	–	non	0,362	F	–	non	2/9
210	M	3,084	M	3,971	M	4,318	M	2,907	M	2,88	M	3,866	M	2,315	M	2,789	M	2,688	M	9/9
266	M	0,574	M	0,594	M	0,671	M	0,503	F	0,373	M	0,267	M	0,492	F	0,418	M	0,185	F	9/9
	correcte		15/28		17/28		17/28		16/28		16/2/		16/28		14/28		17/28		16/28	
	indetermined		13/28		11/28		11/28		11/28		8/28		11/28		11/28		8/28		11/28	
	error		0/28		0/28		0/28		1/28		4/28		1/28		3/28		3/28		1/28	

while it was not possible to apply any of the 9 DFA for 7 skulls. Sex determined on the basis of the first three DFA always corresponded to primary sex diagnosis based on the pelvis. Of the remaining 6 DFA, an error compared to primary sex diagnosis range from 3 cases of the 17 skulls to 4 cases of the total number of 20 skulls determined by DFA. This is an error rate from 18 to 25 %, which corresponds to classification accuracy (Table 6). Based on this test, it can be said that the proposed DFA are reliable and can be used for the purpose to determine sex of skulls in early Slavonic population.

DISCUSSION

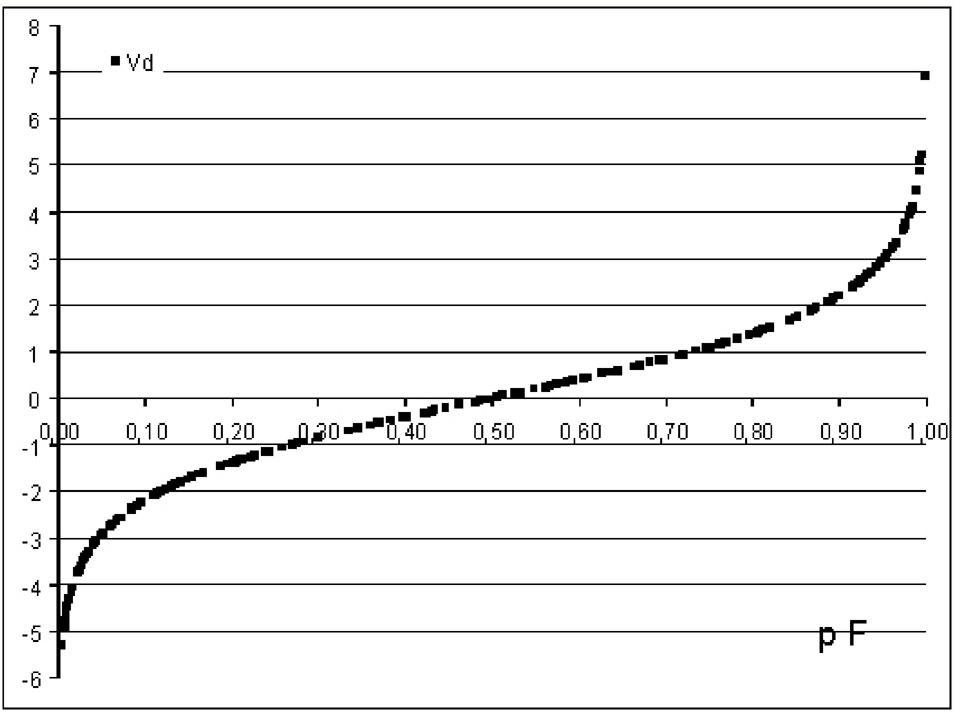
The population specificity of DFA reflects the fact that skeletal sexual dimorphism is influenced by the greater body size, larger joints and stronger musculature of males compared to females in every population. The existence of a secular trend, not only causes variations in body size and stature (body height) between generations (Meadows & Janz 1995, Klepinger 1999), but also has an impact on changes in the measurements of several bones (e.g. Jantz 1999, Bidmos 2005). The DFA calculated in the collection of skeletal remains of known age and sex from individuals living tens or even hundreds of years ago, cannot reflect changes in the sexual dimorphism of body size the past populations living in the same region e.g. 1500 years ago. For this reason the DFA cannot be a general and reliable tool for sex determination.. This is also evidenced by the wrong use of specific discriminant functions derived from measurements of the long limb bones in the recent American population (Işcan & Miller-Shaivitz 1984) and applied to the Neolithic Danish population sample (Götherström et al. 1997). The results of sexing were compared with results of sex determination based on ancient DNA and the discordance of both approaches led to the mistaken rejection of morphometric methods as a whole and unjustified confidence in molecular-genetic methods.

The population-specificity of discriminant functions has also been accentuated in many recent publications (e.g. Bidmos & Dayal 2004, Walrath et al. 2004), yet despite this we are witness to a continuing explosion of proposed morphometric methods which recognise this fact, yet do not respect it (e.g. Asala 2001, Burrows et al. 2003, Šlaus et al. 2003, Bidmos & Asala 2004, Purkait & Chandra 2004, Dayal & Bidmos 2005, Frutos 2005, Kemkes-Grottenthaler 2005). Although these are studies utilise the bone samples from one population, some authors assume or even recommend the general use of these tools without any form of restriction.

In this contribution we have also tried to use the population specificity of cranial measurements to determine sex. The use of the skull for secondary sex diagnosis is just one of the steps that need to be taken to sexing skeletons from the burial sites. Other parts of the skeleton can also be used for this purpose. For this reason we have not analysed the percentage of skeletons from the entire burial site whose sex was determined using DFA skull measurements. This percentage depends on a wider array of factors. We have simply emphasised the demonstrable possibility of reliable sexing of a skull using DFA even in those cases where skeletons of known sex are not available.

However, we must emphasise the difference between statistical accuracy of the classification based on general statistical decisions theory and reliable accuracy of the discrimination (or classification) required by the empirical strategy of anthropological practice. In the overlapping area of DFA values for males and females, it is not possible to decide whether an unknown case for which we wish to determine sex is a true female or a false female, respectively, an incorrectly diagnosed male , as both have the same discriminant score value. In principle, the above two approaches differ in the severity of classification rule applied. In the first of these cases, we use for separation of two groups a posterior probability value equal to 0.50 (the sectioning point), where the degree of certitude of correctly classifying an individual is lower in proximity of the sectioning point. The accuracy is growing that nearer the individual value of Mahalanobis's distance approaches the centroid for the given sex. In the second case of reliable accuracy of the classification, we use a posterior probability value equal to 0.95, which is must severe and resemble to a certitude that the given individual really belongs to the given sex. In practice however, if we cannot apply such severe criteria (small number of individuals, poor preservation of material) we must choose a somewhat lower posterior probability level than 0.95, but which must not fall below 0.70. According to Hanihara (1987) such a probability value

Fig. 2. Example of relationship between probability of sex allocation (axis x) and the discrimination score of DFA 2 (axis y) for female skulls from Mikulčice.



gives a high degree of guarantee of correct sex diagnosis. The risk of misclassification or erroneous diagnosis rises near to the sectioning point.

What sex should be allocated to a skull that could belong to a male with 0.55 probability, if we know that, in such a case, the probability that it is a female skull is 0.45? For the proposed DFA for skulls from old Slavonic populations of the early medieval period, we recommend using the indeterminate sex interval. This approach is illustrated by DFA 2 and the graph showing the relationship between posterior probability and the DFA discrimination score (Fig. 2).

It is clear from the figure that in the discrimination score's interval from –1 to +1 of the sex allocation must be considered as impossible. car the risk of misclassification is very height.

The proposed discriminant functions for the determination of sex based on the skull for early Slavonic medieval populations have a same accuracy indicated for the skull by various authors. This accuracy ranges from 77 % to 85 % (Giles & Elliot 1963, Boulinier 1968, Meindl et al 1985, Steyn & Iscan 1998, Franklin et al. 2005 and others). The accuracy of the discrimination is not however the only criteria affecting the discriminatory power of DFA. Except for biological factors, it is also affected by the size of the sample and number of measurements employed (Van Vark & Schaafsma 1992).

CONCLUSION

The proposed discriminant functions are suitable for determining the sex of early medieval skeletons from the Great Moravian region. They are designed for a quick, preliminary determination of sex of skull in the field work and are a available technique in the absence of the pelvic bone. The accuracy of sex determination is around 80%.

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