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Anthropological and epidemiological characterization of Great-Moravian population in connection with the social and economic structure

Reliable Sex Determination Based on Skeletal Remains for the Early Medieval Population of Great Moravia (9^{th}-10^{th} Century)

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This paper discusses and proposes a reliable sexing technique from an human cranial material for early medieval central European population. The processed discriminant function analysis (DFA) is very accurate and is a population specific tool for sex determination (or exactly estimation). The application of so-called primary and secondary sex diagnosis is necessary and concern a large sample of three Great Moravian graveyards. Only skeletons with preserved hip bone and cranium were employed (n=332). The secondary sex diagnosis uses 12 linear cranial variables commonly employed in other studies using DFA. A set of 9 DFA specific for the studied medieval central European population is proposed. The accuracy of DFA varies from 80,3% (with 4 variables) to 86,1% (with 5 variables). We also carried out a reliability test of the DFA in a small sample 28 skulls whose sex was estimate using a primary sex diagnosis tool. The error rate is in agreement with the observed classification accuracy, around 80%. The proposed DFA can be used in the field for a quick and preliminary sexing of cranial remains or in absence of the pelvic bones in the context of Great Moravian region only (without the influences of asian ethnic groupes).

Key words: Early Medieval population – Great Moravia – sex determination – secondary sex diagnosis – cranial variables

1. Introduction

Sex determination plays a key role in all osteological studies (e.g. Bass 1987; Krogman/Işcan 1986; Buikstra/Ubelaker 1994) and the determining details such as sex, age at death, height or population affinity are the first, basic tasks of skeleton identification (Scheuer 2002). Information on sex affiliation is not only important for bio-archaeological studies of past populations, but also for the archaeological and funeral interpretation of burial sites. Inconsistency in the representativeness of the skeletal group according to sex in relation to the natural mortality in past populations is the subject of palaeodemographic studies. Information on sex affiliation also has an important role in palaeo-epidemiological studies and for assessing the incidence of disease or injuries in populations of the past, indirectly including an appraisal of living conditions, of work activities or of the quality of nutrition in past human populations (e.g. Cohen/Bennett 1998; Grauer/Stuart-Macadam 1998).

It is important to emphasise that any sex determining approach or technique used in the field on the basis of personal and subjective experience can replace the real methods used in the laboratory. Nevertheless, it is always

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recommended to document during excavations (photographs and written records) those parts or details of the skeleton which provide information on the sex of the individual, because there is always a risk of damage during their exposure to climatic conditions, or during the removing phase either when cleaning the skeleton in the laboratory processing.

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; Sjøvold 1988), are population specific. This fact has been pointed out by a number of researchers (already e.g. Henke 1977; Novotný 1981 and more recently e.g. Albanese/Cardoso/Saunders 2005; Işcan et al. 1998), 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 are based on the existence of sexual dimorphism in the skeleton. Sexual dimorphism is caused by the existence of different sex chromosomes and the biological development of males and females. For this reason it is not possible to determine the sex of non-adult individuals with necessary accuracy and reliability as during ontogeny the degree of sexual dimorphism in the skeleton is very low. Nevertheless, the absolute accuracy in sex determination for adult individuals is impossible. The reason is that the existence of numerous anomalies arise during the course of sex differentiation and development of individuals. Another factor is the continuous variability in the development of sex characteristics that contrast with alternative nature of the two sex categories.

With sex diagnosis methods we must therefore distinguish accuracy and reliability, which are varying inversely. This means that increase in accuracy implies decrease in reliability of the sexing and vice versa. The higher accuracy in sex determination results is achieved by using the hip bone, whose sexual dimorphism is stable for all human populations and the methods are reliable with respect of a choice of optimal set of variables from all morpho-functional segments of the pelvis. In the contrary, methods based on «extra-pelvic» variables of the skeleton are specific for a considered population. Their degree of sexual dimorphism is a limiting factor for successful sex determination.

For these reasons, methods proposed for determining sex from the skeleton are not, and cannot be absolutely accurate. There is a generally accepted statement that a single characteristic cannot lead to a reliable result. The accuracy of morphological methods for determining sex is estimated at 80 percent or more ; yet the reliability of these results is sometimes lower. However, the accuracy and reliability of the sexing in anthropology and archaeology must be identical that the arbitrarily set limit of 95% that is a necessity in forensic anthropology (Scheuer 2002; Bruzek/Murail 2006). A high degree of inaccurate sex diagnosis (misclassifications) has a significant affect on taxonomic, archaeological 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 assess and is often a random phenomenon, being sensitive to changes in living conditions, as well as changes of population's genetic structure. These factors are then necessarily reflected in the morphometric characteristics of the human skeleton.

The recommendation for correct and reliable sex determination is primary and secondary sex diagnosis (Murail/Bruzek/Braga 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. Bruzek 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 did not survive 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. Bocquentin 2003; Dittrick/Suchey 1986; Murail 1996; Stojanowski 2003; Wrobel/Danforth/Armstrong 2002). Although the computation of discriminant functions is now very easy thanks to computer technology and software packages, 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 isolated 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.

2. 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 power centre 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

Table 1. List of pelvic variables. The measurements selected for the probabilistic sex diagnosis (DSP) after Murail et al. 2005. Letter 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

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

Abbreviation of Measurements	Measurements	Cranial Measurements	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	n-ba	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-ek	The laterally sloping distance from dacryon (d) to ectoconchion (ec)
M52 (OBH)	Orbital Height		The direct distance between the superior and inferior orbital margins

in the sub-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 (castle) 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 hip bone or a part thereof. A small sample (n = 28) of adult individuals from the Prušánky I burial site with preserved hip bones and skulls were used as a reliability test of the proposed discriminant functions.

Methods – (1) primary sex diagnosis is based on the PSD program (Murail et al. 2005). This involves the calculation of posterior probability for an unknown hip bone, which classifies it as either male or female according to the chosen level of significance. The database contains more than 2 000 hip 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 measurements were taken from the hip bones (Table 1). Sex was allocated using the PSD program only if posterior probability was equal to, or higher, than 0.95.

(2) The secondary sex diagnosis of skulls uses 12 linear measurements according to Martin (Bräuer 1988) and Howells (1996) as

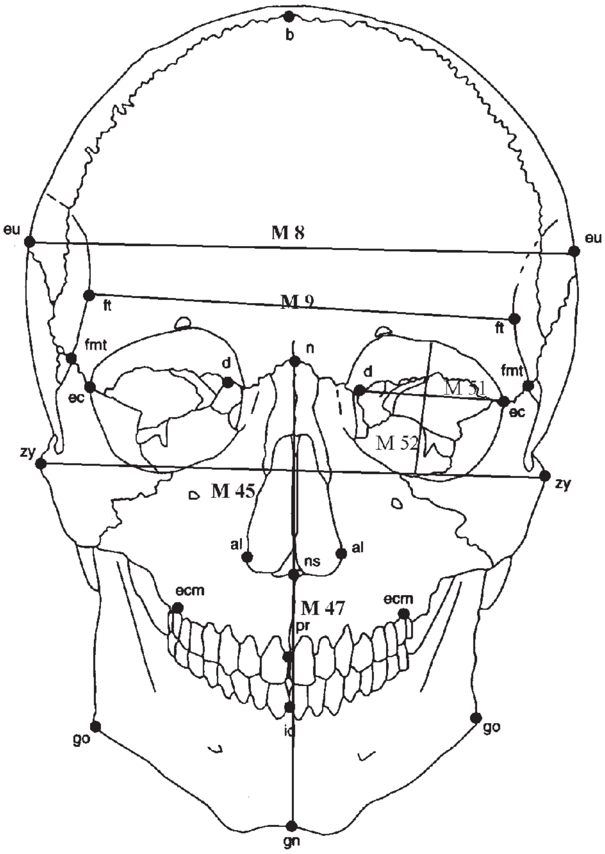

Fig. 1a. Cranial measurements and anthropological points – frontal position.

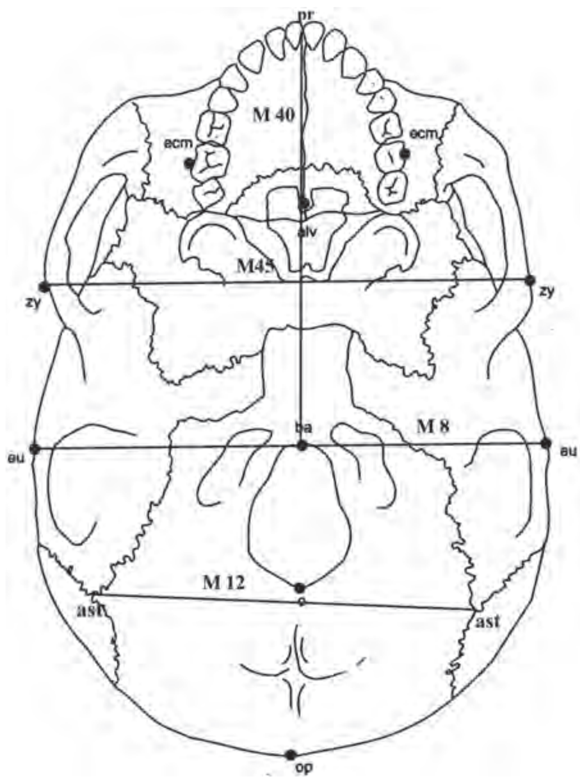

Fig. 1c. Cranial measurements and anthropological points – inferior position.

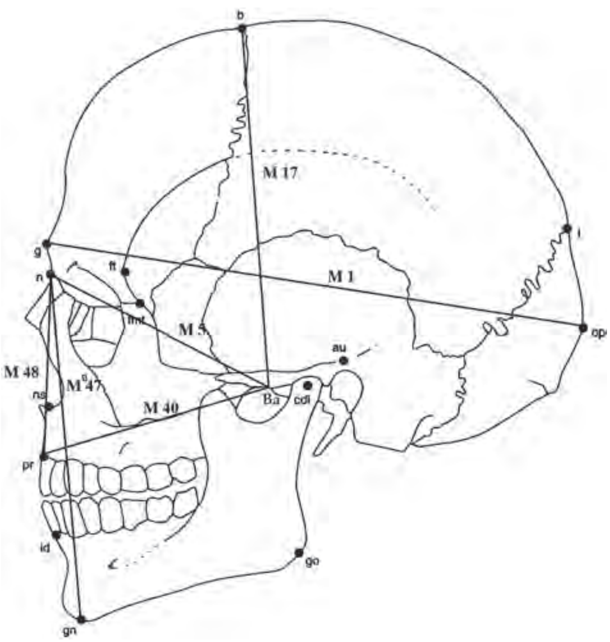

Fig. 1b. Cranial measurements and anthropological points – lateral position.

presented in Table 2 (measurement – abbr. of anthropometric points – definition of measurements – see Fig. 1a-c).

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; Kajanoja 1966; Henke 1974; Giles/Elliot 1963; Šefčáková/Mizera/Thurzo 1999; Franklin/Freedman/Milne 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 computation of discriminant functions and other statistics was carried out using Statistics 7.1. and MS Excel 2003 software.

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

	PSD	PSD	PSD	PSD	PSD	PSD
	Nonaplicable	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 - sub-castle 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%)

Table 4. Summary statistics of cranial variables in the Greath Moravia skeletal sample employed in secondary sex diagnosis (discriminant function analysis).

	Males					Females							
	n1	x	Min	Max	s	n2	x	Min	Max	s	t-test	p	F-test
M1	91	187,9	171	204	6,5	54	179,6	165	193	6,0	8,260	***	1,158560263
M5	80	104,3	91	116	4,7	48	97,5	90	110	3,6	6,758	***	1,716276895
M8	88	142,0	130	155	5,3	54	138,2	128	150	5,2	3,838	***	1,034404893
M9	93	99,9	88	126	5,1	59	96,1	88	103	3,7	3,775	***	1,876589518
M12	82	111,4	100	122	5,2	47	108,4	98	124	5,0	2,995	**	1,105530994
M17	86	137,7	126	160	5,5	52	131,3	122	143	4,5	6,483	***	1,490536199
M40	74	99,0	84	113	5,7	47	93,4	82	105	5,1	5,580	***	1,25439356
M45	72	133,6	101	144	5,8	47	125,8	104	136	6,1	7,817	***	0,895956344
M47	79	120,8	105	136	7,0	49	111,6	98	123	6,4	9,236	***	1,20171464
M48	81	72,6	63	82	12,7	51	67,5	58	77	4,1	6,337	***	9,402885561
M51	81	43,7	37	105	9,7	49	40,5	36	44	2,2	3,202	**	20,2082046
M52	81	35,4	22	102	10,9	49	32,9	28	37	2,0	2,522	*	29,07832265

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)

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.

3. Results

Given the good condition of hip bones (Table 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 hip 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 hip bones. Skeletons with reliable sex diagnosis based on hip bones will be used in secondary sex diagnosis to calculate discriminant analyses based on the skull. The testing sample from Prušánky allowed the

Table 5. Summary statistics of discriminant function analyses (DFA) of cranial variables in pooled sample of Greath Moravian cemeteries from Mikulčice.

Diskriminant Funktion (DF) N°	Number of Variables	Wilk's lambda	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

(a) stepwise DFA of 12 variables
(b) number of variables entered
(M) abbreviation of measurements after Martin (Bräuer 1988)

Table 6. Secondary sex diagnosis – sexing accuracy for discriminant function 1-9 for the pooled sample of Great Moravia skulls (Mikulčice-Valy and Mikulčice-Kostelisko Cemeteries).

Discriminant Function (DF) N°	Number of Variables	Variables	Males		Females		Correctly Assigned	
			N	%	N	%	N	%
DFA 1	4	M 1, 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 45	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	82.9	92 / 108	85.2
DFA 9 (a)	5	M 5, M 17, M 45, M 47, 51 (b)	54 / 64	84.4	33 / 40	82.5	87 / 104	83.7

(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)

sex determination of skull from 28 individuals determined by primary sex diagnosis.

Secondary sex diagnosis (SSD) 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,

Table 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 the Table 2.

Discriminant Function (DF) N°	Equation	Classification p = 0,5	Centroid
DFA 1	(M 1 * -0,159) + (M 40 * -0,044) + (M 45 * -0,180) + (M 48 * -0,037) + 59,478	F > 0 > M	2.983
DFA 2	(M 1 * -0,098) + (M 5 * -0,196) + (M 8 * -0,005) + (M 45 * -0,164) + (M 48 * -0,034)+ 62,209	F > 0 > M	3.417
DFA 3	(M 1 * -0,088) + (M 5 * -0,206) + (M 8 * -0,023) + (M 45 * -0,158) + 60,607	F > 0 > M	3.256
DFA 4	(M 1 * -0,123) + (M 17 * -0,183) + (M 45 * -0,151) + 66,829	F > 0 > M	3.331
DFA 5	(M 1 * -0,183) + (M 8 * +0,001) + (M 45 * -0,183) + (M 52 * -0,046) + 58,784	F > 0 > M	2.270
DFA 6	(M 1 * -0,124) + (M 5 * -0,163) + (M 8 * -0,093) + (M 12 * +0,111) + (M 17 * -0,228)+ 70,583	F > 0 > M	3.877
DFA 7	(M 1 * -0,143) + (M 8 * -0,053) + (M 17 * -0,184)+ 58,446	F > 0 > M	2.555
DFA 8	(M 1 * -0,186) + (M 8 * +0,013) + (M 45 * -0,191) + (M 48 * -0,039) + 60,001	F > 0 > M	3.052
DFA 9	(M 17 * -0,126) + (M 47 * -0,106) + (M 5 * -0,197) + (M 45 * -0,109) + (M 51 * -0,053)+ 65,354	F > 0 > M	4.033

whose basic statistics are given in Table 4. There were significant sex differences in all of the measurements studied in the skulls from Mikulčice (Table 4). The average value of measurements is significantly higher for males than for females.

We calculated nine 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 four measurements, of which two describe the neurocranium and two the face. The second DFA combines three measurements of the neurocranium with two measurements of the face. The third DFA is a modification of the second DFA with three measurements of the neurocranium and the width of the face, while the fourth DFA only uses three cranial measurements. The fifth DFA uses four measurements, two of the neurocranium and two 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 five 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).

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 males and 61 females whose sex was determined according to the pelvis, as individuals with incomplete data were removed from the calculation.

Table 8. Test of the discriminant function analyses of cranial variables in population sample from Prušánky burial-ground (classification rule: p = 0,5). 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

N° grave	"PSD"	DFA 1	sex	DFA 2	sex	DFA 3	sex	DFA 4	sex	DFA 5	sex	DFA 6	sex	DFA 7	sex	DFA 8	sex	DFA 9	sex	Applica-bility	"SSD"
10	F	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9F
58	F	-	?	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	8F
61	F	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9F
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	7F
174	F	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	0/9	?
182	F	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9F
214	F	-	?	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	8F
251	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	7F
252	F	-	?	-	?	-	?	-	?	2.743	M *	-	?	-	?	2.408	M *	-	?	2/9	2M
283	F	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9M
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	9M
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	9M
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	9M
64	M	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	0/9	?
65	M	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9M
84	M	-	?	-	?	-	?	-	?	0.354	F *	-	?	-	?	0.446	F *	-	?	2/9	2F
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	9M
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	9M
154	M	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	-	?	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	9M
189	M	-	?	-	?	-	?	-	?	0.083	F *	-	?	-	?	0.362	F *	-	?	2/9	2F
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	9M
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	7M
correct			*15/28*		*17/28*		*17/28*		*16/28*		*16/28*		*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*		

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 – Maximum Cranial Length) and bizygomatic facial width (M45 - Bizygomatic Width) 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 indicate 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.

To verify the accuracy of the proposed DFA, we carried out a reliability test on a small sample of 28 skulls (13 females and 15 males) from the Prušánky I burial site, whose sex was determined in advance by PSD. The Prušánky I burial site is located in the hinterland of the Mikulčice centre 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, while it was not possible to apply any of the 9 DFA for seven 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 three cases of the 17 skulls to four 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 (determining sex of skulls in early Slavonic population) (for which they were presumed).

4. 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 a considered population. The existence of a secular trend, not only causes variations in body size and stature (body height) between generations (Meadows/Janz 1995; Klepinger 2001), but also has an impact on changes in the measurements of several bones (e.g. Jantz 1999; Bidmos 2006). 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 for example 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 by Işcan/Miller-Shaivitz (1984) and applied to the Neolithic Danish population sample by 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 an erroneous rejection of morphometric methods as a whole and unjustified confidence in molecular-genetic methods (Götherström et al. 1997).

The population-specificity of discriminant functions has also been accentuated in many recent publications (e.g. Bidmos/Dayal 2004;

WALRATH/TURNER/BRUZEK 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; BIDMOS/ASALA 2004; BURROWS/ZANELLA/BROWN 2003; KEMKES-GROTTENTHALER 2005, PURKAIT/CHANDRA 2004; ŠLAUS et al. 2003; FRUTOS 2005; DAYAL/BIDMOS 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 discrimination (or classification) based on general statistical decisions theory and reliable accuracy of the discrimination (or classification) required by the empirical strategy of anthropological practice. For each application of discriminant function, sex assessment of a new case depends on the computation of a discriminant score (DS) which is compared to the discriminant value (DV) separating males from females. 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

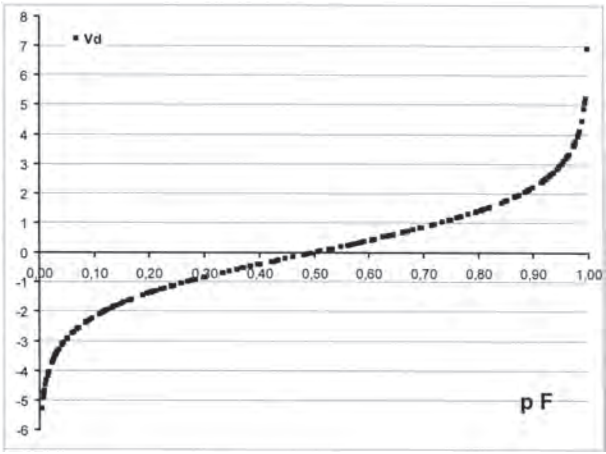

Fig. 2. Example of relationship between probability of sex allocation (axis x) and the posterior probability or discrimination score of DFA 2 (axis y) for female skulls from Mikulčice.

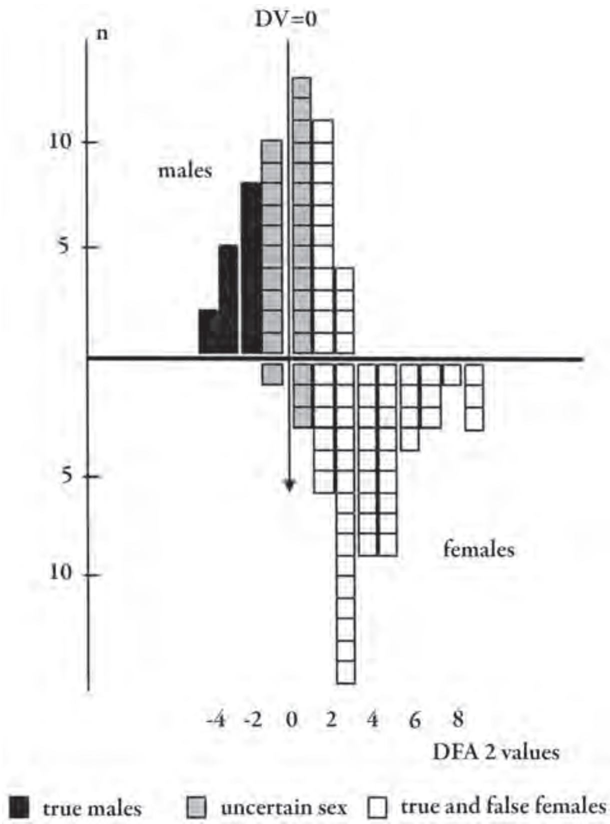

Fig. 3. The shift of distribution accuracy in correctly determining sex for a group of skulls from Coimbra collection of identified skeletons using a DFA 2 from the “Great Moravian” population.

is lower in proximity of 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 (1981) such a probability value gives a high degree of guarantee of correct sex diagnosis. The risk of misclassification or erroneous diagnosis rises near to the sectioning (dividing) 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 in which the posterior probability for male and female diagnosis is very close. This approach is illustrated by DFA 2 and the graph showing the relationship between posterior probability and the distribution of the discriminant scores (Figure 2).

It is evident from the graph that the sex allocation is uncertain in interval of the discrimination score values from –1 to +1. In this interval the sex must be considered as indeterminate. In order to confirm the population specificity of the proposed discriminant functions, we have presented the results of a simple test. Once again we chose DFA 2 and using this function tried to determine the sex of recent adult skulls of known sex and age originating from Portuguese Coimbra. This involved the skulls of 107 individuals (53 males and 54 females) which were measured by one of the authors (Bruzek et al. 2004) and which were used previously for testing the ForDisc 2.0 program (Ousley/Jantz 1996). As shown in Graph (Figure 3), the sex of only 28% of male skulls (15 of 53) was reliably determined using "Great Moravian" DFA 2. This was significantly better for the females in the group, where DFA 2 confirmed the sex of almost 93% of female skulls (50 of 54). It is also evident from Graph (Figure 3) that 23 males and 4 females out of the 107 individuals tested fell in the interval of "uncertain or indeterminate values", i.e. the overlap zone, with discriminant scores of -1 to +1. These results confirmed the population specificity of Great Moravian DFA 2. Sexual dimorphism exists in both groups, that is, both the Great Moravian and recent Portuguese group; however the size factor shifts the discriminant value of DFA 2 towards male individuals, which means the Portuguese skulls are finer.

For comparison, we calculated a discriminant function for the set of skulls from Coimbra based on identical measurements as those used for the "Great Moravian" DFA 2 and the resulting classification correctly identified 88% of individuals. The test confirms the population specificity of DFA cranial measurements and the suitability of secondary diagnosis in every population.

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% (Boulinier 1968; Giles/Elliot 1963; Meindl et al 1985; Steyn/Işcan 1998; Franklin/Freedman/Milne 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).

When determining sex and evaluating the accuracy of the used methods, archaeological and cultural aspects must also be taken into consideration. There is a consensus in biological anthropology in which sex is a biological category determined at the moment of conception which is a process of sex differentiation and development, also of a biological nature, that allows us to distinguish between male and female individuals. On the other hand, gender is a category or a cultural and social construction according to which individuals are classified or considered as men or women. An individual gender identity and social position are also dependent on the psychological factors and «brain gender». In many human societies, the position of the man (male gender) is more advantageous as it is associated with better living conditions. There are also societies that recognise more than two sexes and individuals can go from one category to another during their life. Although rare, such cases do exist and in the archaeological context may explain the inability to obtain absolute agreement between sex and gender. According to Gauthier (2000), an autopsy of Vittoria Colonna's mummy, the wife of Ferdinando d'Avalos, who lived in the 16th century in Italy, revealed that it was in reality a man. For this reason it is important to clearly distinguish between sexes as a biological category according to which we classify human remains and the gender as a psycho-social category of the person during his/her lifetime (Taylor 1998). It is thus impossible to expect absolute sex determination of male and female individuals on the basis of somatic sex criteria. Therefore it is generally allowed that the 95% threshold represent the maximum success of sex diagnosis on the basis of the skeleton.

Classic multivariable statistical tools such as discriminant function analysis, do not allow the overly successful differentiation of two population groups of skulls due to extensive intra population variability, which is greater than the actual differences between the groups (Bruner/Ricci/Manzi 2002). New methods such as geometric morphometry have an advantage over multivariable statistics in that they can localise the area of the cranium whose morphometric characteristics most contributed to the differentiation of the group of skulls (Ross/McKeown/Konigsberg 1999). Significant biological differences in cranial shape, ascertained using geometric morphometry, allowed the authors, for example, to explain the population affinity of the Cuban population of the 19th century and contribute to identification criteria for the South Florida population of Cuban Americans (Ross et al. 2004). Although this primarily relates to the American population and estimated population affinity, it can be assumed that geometric morphometry can also be used in anthropology studying sexual dimorphism and its applications, which includes the sex determination of individuals from past human populations.

5. Conclusion

The proposed discriminant functions are suitable for determining the sex of early medieval skeletons from the Great Moravian region only (without the influences of nomadic asian peoples). 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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