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LUDOVIC DEBONO, BERTRAND MAFART

SEX DETERMINATION FROM FRAGMENTED HIP BONES USING THE BRUZEK METHOD: EXPERIENCE IN A HISTORIC NECROPOLIS IN PROVENCE (FRANCE)

ABSTRACT: The most reliable methods of determining sex from skeletal remains are based on examination of the hip bone. However, hip bone specimens may be incomplete or fragmented. The purpose of this study was to identify the best-preserved regions of the hip bone with the greatest diagnostic value for sex determination.
The Bruzek method of visual sex determination using 11 anatomic hip bone features was applied to a sample of 963 hip bones from the Notre-Dame-du-Bourg necropolis dating from the fourth to seventeenth centuries AD in Provence (Digne, France). Assessment of the value of various regions of the hip bone for sex determination in function of the degree of preservation showed that the ischiopubic pelvis complex was highly informative but often unavailable whereas the posterior region of the os coxae *was as informative and much better preserved. This finding indicates that priority care should be given to the posterior coxal bone during exhumation.*

KEY WORDS: Human pelvis – Hip bone – Sex determination – Method

INTRODUCTION

The best methods for determining sex from adult skeletal remains involve measurement and inspection of the hip bone that presents a number of gender-related anatomical differences (Ferembach *et al*. 1980). Numerous sex determination techniques have been proposed based either on examination of specific parts of the hip bone including the pubic bone (Phenice 1969), sciatic notch (Kelley 1979), sacro-iliac joint (Iscan, Derrick 1984, Ali, Maclaughlin 1991), acetabulum (Schulter-Ellis *et al.* 1983, 1985) or innominate bone (Schulter-Ellis *et al.* 1983, 1985) or on examination of the whole hip bone (Bruzek 2002, Ferembach *et al.* 1980, Albanese 2003).

However, a major problem for sex determination is that hip bones are often incomplete or damaged. Problems posed by sex determination using fragmented hip bones have been given little attention in the literature (Iscan, Derrick 1984). Our experience in studying a large burial site from the historic period in Provence (southern France) provided an opportunity to analyze the extent of bone fragmentation and its impact on sex determination.

The threefold purpose of this study was (i) to evaluate the efficacy of the Bruzek method for sex determination in an archaeological sample, (ii) to analyse the loss of diagnostic data in "naturally" fragmented bones and (iii) to identify the most reliable criteria in function of preservation and diagnostic value. The Bruzek method of sex determination (Bruzek 2002) is based on a combination of non-metric features and osteoscopic assessment of proportions. The reported success rate of this method in a sample of complete hip bones of known sex was 98%.

MATERIAL

This study involves an archaeological sample collected from a historic gravesite investigated by Gabrielle Démians d'Archimbaud (Démians d'Archimbaud 1992) at Notre-Dame-du-Bourg in Digne (Alpes-de-Haute-Provence, France). Anthropological and paleopathological study of this historic sample has been headed by B. Mafart at the Institut de Paléontologie humaine, Laboratory of Marseille (France) and publication of scientific findings is under way. A total of 1,223 adults were exhumed from 1,011 graves dating from the fourth to seventeenth centuries AD. All useable adult hip bones were studied, i.e. 963 hip bones from 632 individuals (*Table 1*).

METHOD

Hip bones were evaluated by the two investigators using the Bruzek method of visual sex determination (*Table 2*) based on a combination of 11 features (S1 to S11) divided into five groups (A to E). Each feature was scored as male, female or inconclusive. Traits are:

S1: development of negative relief on preauricular surface,
f – deep depression well-delimited (pits),
i – intermediate form,
m – relief smooth or very slightly negative relief.
S2: aspect of grooves or pitting,
f – pits or groove with closed circumference,
i – intermediate form,
m – depression with open circumference.
S3: development of positive relief on preauricular surface,
f – lack of tubercle,
i – intermediate form,
m – turbercle present or clear protuberance.
S4: proportion of length of sciatic notch chords,
f – posterior chord segment longer than or equal to anterior chord,
i – intermediate form,
m – posterior chord shorter than anterior chord.
S5: form of contour notch chords,
f – symmetry relative to depth in basal portion of sciatic notch,
i – intermediate form,
m – asymmetry relative to depth of sciatic notch.
S6: contour of posterior notch chord,
f – outline (contour) of posterior chord does not cross perpendicular line,
i – intermediate form,
m – contour of posterior chord crosses perpendicular line.
S7: relation between outline of sciatic notch and outline of auricular surface,
f – double curve,
i – intermediate form,
m – single curve.
S8: characterization of *margo inferior ossis coxae,*
f – external eversion,
i – intermediate form,
m – direct course of medial part.

TABLE 1. Sample studied from Notre-Dame-du-Bourg necropolis.

	Hip bones	Individuals
All adults found in necropolis		1223
All pelvises observable	963	632
Hip bones with at least 3 groups observable	494	

TABLE 2. Number and preservation of diagnostic traits in 963 hip bones from an archaeological population.

Groups	Categories			Traits			
		Number present	Preservation rate (%)	Traits		Number present	Preservation rate (%)
Preauricular surface	A	925	96.1%	Paraglenoid groove	S1	854	88.7%
				Preauricular groove	S2	921	95.6%
				Piriform tubercle	S3	825	85.7%
Greater sciatic notch	B	835	86.7%	Proportion of length of sciatic notch chords	S4	802	83.3%
				Form of contour notch chords	S5	823	85.5%
				Contour of posterior notch chord	S6	822	85.4%
Composite arch	C	879	91.3%	Composite arch	S7	879	91.3%
Inferior pelvis	D	390	40.5%	*Margo inferior ossis coxae*	S8	351	36.4%
				Phallic ridge	S9	353	36.7%
				Ischio-pubic ramus aspect	S10	385	40.0%
Ischiopubic proportion	E	347	36.0%	Ischio-pubic proportion	S11	347	36.0%

S9: absence or presence of the phallic ridge,
f – lack of the phallic ridge or presence of only little mound,
i – intermediate form,
m – clear presence of the phallic ridge.
S10: ischio-pubic ramus aspect,
f – gracile aspect,
i – intermediate form,
m – robust aspect.
S11: relation between *pubis* and *ischium* lengths,
f – *pubis* longer than *ischium,*
i – intermediate form,
m – *ischium* longer than *pubis.*

Positive diagnosis was achieved if a majority of groups, i.e. 3 or 5, were conclusive for the same sex. If there was no majority score, the sample was considered as unclassifiable.

To assess the accuracy of the Bruzek method for sex determination using fragmented hip bones, the study was focused on a reference sample of 494 hip bone specimens sharing three or more identical diagnostic features. In this sample we compared the score of each feature to the final diagnosis that was considered as valid. Success rates were calculated for all possible feature combinations. Statistical analysis was performed using the Chi-square test evaluated at the conventional level of alpha = 0.05.

RESULTS

Hip bone evaluation was possible for only 51.6% (632/1223) of the skeletons exhumed from the gravesite. Preservation of the anatomical regions used for sex determination was highly variable (*Table 2*). Due to its hardness the posterior part of the coxal bone with the sciatic notch was the best-preserved region, with all features in all three groups (A, B and D) being present in over 83% of cases. Preservation of the ischiopubic complex region (groups D and E) was much lower, with all features in the two groups being present in 36% of cases.

The incidence of various combinations of diagnostic features was highly variable (*Table 3*). Of the 31 possible combinations, two, i.e. ABCDE and ABC, were found in 75% of cases and 11 combinations in 95% of cases. Nine combinations were almost never encountered.

The 963 hip bone specimens were classified as male in 479 cases (49.7%) and female in 398 cases (44.3%). The remaining specimens (8.9%) were considered to be unclassifiable. The predominance of males in this archaeological sample is probably linked to the better preservation of stronger male hip bones. This explanation is supported by the higher incidence of hip bones with more than one missing feature group in females (n=270, i.e. 67.8%) than in males (n=256, i.e. 53.5%). This difference was highly significant (Chi-square test, p<0.001).

In 83% of cases sex determination was the same on the left and right sides (*Table 4*). In 4% of cases determination demonstrated male sex on one side and female sex on the other. The rate of discordance was similar to that reported by Bruzek and did not constitute a drawback for the use of the method. In 13% of cases (45/353) one side was inconclusive.

Using the Bruzek method of sex determination is based on agreement of a majority of groups. If 3 of the 5 groups are concordant, the sex is considered as established regardless of the results of the other 2 groups. In the sample from Notre-Dame-du-Bourg, sex determination based on concordance of at least 3 groups was feasible in only 494 of the 963 hip bones (51.2%). This sample of 494 hip bones in which accuracy can theoretically be considered as 98% certain was used to analyse the diagnostic value of each feature and feature combination. *Table 5* shows the distribution of confidence rates in the reference sample of 494 hip bones. The Bruzek method was highly reliable since the confidence rate was over 90% in 87.5% of hip bones. Care is necessary for the 32 hip bones (3.3%) that were unclassifiable.

The diagnostic value of the different features used for sex determination was variable (*Tables 5* and *6*). Feature S1 presented the least diagnostic value and the value of S3, S8 and S10 was less than 73%. The most effective features were S4 and S11. Feature group B was by far the most reliable in terms of feature availability (present in over 83%), inconclusive rate, and diagnostic accuracy. Feature S11 (ischio-pubian proportion) was the most accurate (95%) but was often unavailable (present in 30.9%). Feature S4 (proportion of length of sciatic notch chords) exhibited similar accuracy (95%) with better availability (absent in 2.8%). *Table 6* also lists the diagnostic value of each feature according to sex. For female sex S8 and S9 were the most sensitive features (60.7 and 57.4%, respectively) and S1 was the most specific (46.6%). For male sex the most outstanding finding was the extremely poor sensitivity of feature S1.

To rate the features in terms of both diagnosis and preservation, a coefficient of efficacy was calculated by first multiplying the preservation rate by the success rate and then multiplying the product by 100. Five features had ratings over 79%, i.e. S2, S4, S5, S6 and S7. These 5 features were used for sex determination in an abridged version of the Bruzek method. The results obtained using the complete and abridged Bruzek methods were concordant in 458 of the 494 hip bones (92.7%) and discordant in two cases (0.2%). In 34 cases (6.9%) the abridged method was inconclusive while the complete method was conclusive. Overall in the whole archaeological sample, the accuracy of the abridged method was lower than that of the complete method, i.e., 81.1% vs. 92.7%, but the left–right discordance rate was the same, i.e. 0.6%. Although the unclassifiable rate was higher than the complete method, i.e. 15.2% vs. 8.9%, the abridged method allowed sex determination in some cases (3.1%) in which the Bruzek method was inconclusive.

Sex determination was based on agreement of the majority of groups for the same sex. *Tables 3* and *5* indicate the degree of diagnostic accuracy.

TABLE 3. Prevalence of different combinations in overall sample and accuracy of sexing of hip bones specimens from the archaeological sample in function of the number of trait groups present.

Diagnostic features		Prevalence in overall sample		Accuracy of diagnostic in the reference group of 494 hip bone specimens		
				Total number of cases	Number of successful cases	
All groups present	A B C D E	313	32.5%	278	278	100.0%
One group missing	A B C D	40	4.2%	305	298	97.7%
	A B C E	4	0.4%	280	276	98.6%
	A B D E	9	0.9%	284	278	97.9%
	A C D E	3	0.3%	281	276	98.2%
	B C D E	3	0.3%	280	275	98.2%
Two groups missing	A B C	434	45.1%	482	466	96.7%
	A B D	2	0.2%	311	292	93.9%
	A B E	0	0.0%	286	279	97.6%
	A C D	0	0.0%	308	287	93.2%
	A C E	0	0.0%	283	271	95.8%
	A D E	2	0.2%	288	275	95.5%
	B C D	0	0.0%	282	277	98.2%
	B C E	0	0.0%	282	277	98.2%
	B D E	0	0.0%	286	273	95.5%
	C D E	2	0.2%	283	271	95.8%
Three groups missing	A B	21	2.2%	488	451	92.4%
	A C	62	6.4%	485	438	90.3%
	A D	4	0.4%	315	266	84.4%
	A E	0	0.0%	290	255	87.9%
	B C	4	0.4%	484	449	92.8%
	B D	0	0.0%	313	278	88.8%
	B E	0	0.0%	288	262	91.0%
	C D	2	0.2%	310	268	86.5%
	C E	0	0.0%	285	256	89.8%
	D E	9	0.9%	290	257	88.6%
Four groups missing	A	31	3.2%	492	395	80.3%
	B	5	0.5%	490	463	94.5%
	C	11	1.1%	487	428	87.9%
	D	1	0.1%	317	242	76.3%
	E	1	0.1%	292	270	92.5%

TABLE 4. Success rate in function of the side of hip bone specimens.

Different diagnoses	Number	%
Identical diagnoses on both sides	293	83%
Diagnosis with indeterminate one side	45	13%
Inconsistent diagnoses	15	4%

DISCUSSION

The sex determination method proposed by Bruzek (Bruzek 2002) takes into account a number of anatomic features of the hip bone. According to the author, diagnostic accuracy is excellent when the complete hip bone is available. The method was developed using two European population samples (French and Portuguese) from the 19th and 20th centuries. These populations can thus be considered as fairly close both geographically and temporally to the population from Notre-Dame-du-Bourg. Although diachronic and geographic differences with the reference sample in the expression of sex-related anatomical features cannot be ruled out, the use of Bruzek method in our sample seems valid since hip bone features used for sex determination seem to be fairly stable across population groups (Kelley 1979). The fact that sex determination in the present study sample was based solely on the Bruzek

TABLE 5. Accuracy of diagnostic traits in the reference group of 494 hip bone specimens from an archaeological population.

						Male			Female		
	Number present	**Preservation rate (%)**	**Accurate diagnosis**	**Success rate (if present)**	**Indetermined**	**Accurate diagnostic**	**Inac-curate diagnostic**	**Success rate**	**Accurate diagnostic**	**Inac-curate diagnostic**	**Success rate**
S1	475	96.2%	282	59.4%	52 (10.5%)	72	6	92.3%	210	135	60.9%
S2	491	99.4%	414	84.3%	49 (9.9%)	230	17	93.1%	184	11	94.4%
S3	464	93.9%	326	70.3%	96 (19.4%)	169	24	87.6%	157	18	89.7%
S4	483	97.8%	459	95.0%	8 (1.6%)	256	14	94.8%	203	2	99.0%
S5	490	99.2%	406	82.9%	54 (10.9%)	260	28	90.3%	146	2	98.6%
S6	487	98.6%	391	80.3%	61 (12.3%)	178	7	96.2%	213	28	88.4%
S7	487	98.6%	428	87.9%	40 (8.1%)	212	4	98.1%	216	15	93.5%
S8	297	60.1%	204	68.7%	38 (7.7%)	139	29	82.7%	65	26	71.4%
S9	296	59.9%	228	77.0%	34 (6.9%)	166	28	85.6%	62	6	91.2%
S10	313	63.4%	228	72.8%	60 (12.1%)	137	7	95.1%	91	18	83.5%
S11	292	59.1%	270	92.5%	11 (2.2%)	174	7	96.1%	96	4	96.0%
A	492	99.6%	395	80.3%	75 (15.2%)	182	5	97.3%	213	17	92.6%
B	490	99.2%	463	94.5%	12 (2.4%)	257	13	95.2%	206	2	99.0%
C	487	98.6%	428	87.9%	40 (8.1%)	212	4	98.1%	216	15	93.5%
D	317	64.2%	242	76.3%	54 (10.9%)	162	15	91.5%	80	6	93.0%
E	292	59.1%	270	92.5%	11 (2.2%)	174	7	96.1%	96	4	96.0%

TABLE 6. Accuracy of diagnostic traits in the reference group of 494 hip bone specimens according to sex.

	Male						Female					
	Accurate diagnostic	**Inaccurate diagnostic**	**Success rate**	**Sensibility**	**Specificity**	**Likehood ratio (sensibility/ 1–specificity)**	**Accurate diagnostic**	**Inaccurate diagnostic**	**Success rate**	**Sensibility**	**Specificity**	**Likehood ratio (sensibility/ 1–specificity)**
S1	72	6	92.3%	28.5%	97.3%	10.53	210	135	60.9%	94.6%	46.6%	1.77
S2	230	17	93.1%	87.1%	92.5%	11.63	184	11	94.4%	81.1%	95.8%	19.45
S3	169	24	87.6%	69.5%	89.1%	6.40	157	18	89.7%	71.0%	92.6%	9.59
S4	256	14	94.8%	98.8%	93.8%	15.81	203	2	99.0%	90.6%	99.2%	117.36
S5	260	28	90.3%	98.5%	87.6%	7.95	146	2	98.6%	64.6%	99.2%	85.27
S6	178	7	96.2%	68.2%	96.9%	22.02	213	28	88.4%	94.2%	89.3%	8.79
S7	212	4	98.1%	81.5%	98.2%	46.27	216	15	93.5%	95.2%	94.2%	16.49
S8	139	29	82.7%	73.2%	72.9%	2.70	65	26	71.4%	60.7%	86.3%	4.44
S9	166	28	85.6%	88.3%	74.1%	3.41	62	6	91.2%	57.4%	96.8%	17.99
	137	7	95.1%	69.2%	93.9%	11.37	91	18	83.5%	79.1%	90.9%	8.70
	174	7	96.1%	94.1%	93.5%	14.38	96	4	96.0%	89.7%	97.8%	41.50
A	182	5	97.3%	68.7%	97.8%	31.18	213	17	92.6%	93.8%	93.6%	14.63
B	257	13	95.2%	97.3%	94.2%	16.92	206	2	99.0%	91.2%	99.2%	120.32
C	212	4	98.1%	81.5%	98.2%	46.27	216	15	93.5%	95.2%	94.2%	16.49
D	162	15	91.5%	80.2%	87.0%	6.15	80	6	93.0%	69.6%	97.0%	23.42
E	174	7	96.1%	94.1%	93.5%	14.38	96	4	96.0%	89.7%	97.8%	41.50

method without verification, suggests that a degree of caution is necessary.

Less than one third of the hip bones studied presented all five groups used for sex determination according to the Bruzek method. Nevertheless, our experience showed that sex determination could be achieved on fragmented hip bones based on incomplete data.

The use of the Bruzek method in our study population revealed several shortcomings related to the features used for sex determination. The anatomical definitions of some features were difficult to apply. Due to the high frequency of this problem, the diagnostic efficacy of the paraglenoid groove (S1) was poor and its success rate of only 59.4% was barely higher than a chance for binary male/female diagnosis. Another feature-related problem was inconclusive diagnosis. This problem greatly reduced the diagnostic value of S1, S3, S6 and S10.

In this study the most useful part of the hip bone for sex determination was the sacro-iliac complex (features A, B, and C). The sciatic notch was particularly informative and well preserved. Conversely, the ischio-pubic pelvis complex was poorly preserved and thus not well suited for use in an archaeological population. According to our experience, S2, S4, S5, S6 and S7 were the 5 best features that in combination allowed the most accurate sex determination.

This study demonstrated that sex could be satisfactorily determined even on a fragment of hip bone since the diagnostic value of all features (except for S1 that was poorly productive) achieved a success rate greater than 70% and even 75% when only the groups were used. To ensure greater certainty, e.g. to achieve 95% accuracy, S4 (proportion of length of sciatic notch chords) and at least 3 categories out of 5 must be available.

This paper does not test the accuracy of the Bruzek method for the sex determination that should need further investigations with known sex samples from different populations of the world. It would be a circular argument to use a sample of unknown sex to test a sexing method. This study is focused on the specific problems of the archaeological sample for which the different methods for sex determination are always used without any possibility of testing them on a known sex sample.

Any loss of information, no matter how small, has an adverse impact on the rate of successful sex determination, whatever the method used. The posterior region of the hip bone including the sciatic notch is particularly informative, especially since the sacro-iliac joint can also be used to evaluate another essential parameter, i.e. the age at death (Lovejoy *et al.* 1985, Osborne *et al*. 2004). Special care of this region must be recommended during excavation. The posterior region must be thoroughly examined when the remains are exhumed to ensure the most reliable sex determination possible.

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Ludovic Debono
Laboratoire d'Anthropologie
anatomique et de Paléopathologie
Université Rockfeller
8 avenue Rockfeller
63373 Lyon 8, France
E-mail: ludovic@debono.fr

Bertrand Mafart
Antenne de l'Institut
de Paléontologie humaine
Europôle de l'Arbois
BP 80
13545 Aix-en-Provence cedex 04, France
E-mail: Mafartbertrand@aol.com