ANTROPOLOGIA PORTUGUESA

Colecções Osteológicas do Museu Antropológico da Universidade de Coimbra

Vol. 13
1995

DEPARTAMENTO DE ANTROPOLOGIA
UNIVERSIDADE DE COIMBRA

Antrop. Port., 13. 1995: 171-191

Sexual dimorphism of the hip bone in the Coimbra population (Portugal)

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Abstract. A large sample of hip bones of known sex comming from one modern population is studied morphologically and by multivariate analysis to investigate sexual dimorphism patterns. A principal component analysis of raw data shows that a large amount of the hip bone sexual dimorphism is accounted for by size differences, but that sex-linked shape variation is also very conspicuous and cannot be considered an allometric consequence of differences in body size between the sexes. The PCA of transformed ('shape') variables indicates that the female hip bones are different in those traits associated with a relatively larger pelvic inlet (longer pubic bones, a greater degree of curvature of the iliopectineal line and a more posterior position of the auricular surface), as well as a broader sciatic notch. The analysis of non-metric traits also shows marked sexual dimorphism in the position of the sacroiliac joint in the iliac bone, in the shape of the sciatic notch, in pubic morphology, and in the presence of the pre-auricular sulcus in females.

Key Words: sexual variability; obstetrics; principal components; pelvimetry; allometry.

Resumo. No presente artigo investiga-se o padrão morfológico de dimorfismo sexual de uma grande série de ossos coxais de sexo conhecido, proveniente de uma população moderna, através de análise multivariada. A análise de componentes principais, (ACP), mostra que grande parte do dimorfismo sexual do osso coxal é explicado por diferenças de tamanho mas que a variação na forma ligada ao sexo é também conspícua e não pode ser uma consequência alométrica das diferenças de tamanho corporal entre os sexos. A ACP das variáveis transformadas indica que os ossos coxais femininos diferem nos caracteres associados a uma abertura pélvica relativamente grande (ossos púbicos compridos, um maior grau da curvatura da linha iliopectínea e numa posição mais posterior da superfície auricular), assim como uma maior chanfradura ciática. A análise dos caracteres não métricos mostra também um acentuado dimorfismo sexual na inserção do ligamento sacro-ilíaco no osso ilíaco, na forma da chanfradura ciática, na morfologia púbica e na presença do sulco pré--auricular nas mulheres.

Palavras-chave: variabilidade sexual; obstretricia; componentes principais; pelvimetria; alometria.

Introduction

Sexual dimorphism in the hip bone has been studied by many authors (see Genovés, 1959, Segebarth-Orban, 1980, Arsuaga, 1985a, Krogman and Iscan, 1986). However, sexual dimorphism in the human hip bone is not only a matter of size or robustness. Shape differences are also very conspicuous, but in order to properly appreciate them it is necessary to eliminate first the size factor, and this usually has been done by constructing indices. Multivariate analysis can better help to achieve this goal and deal with many variables at the same time, allowing the study of the human hip bone as a system.

Material and methods

In this paper, we present the results of a univariate, multivariate and non--metrical study of a large modern human sample of hip bones. Thirty four linear variables were measured and ten non-metrical (morphological) characters recorded (Figure 1 and Appendix) in a series of 418 adult hip bones of known sex (227 males and 191 females), born in the Beira Litoral region of Portugal between 1820 and 1920. This skeletal collection is kept in the Museu Antropólogico da Universidade de Coimbra (Portugal). Serra (1938) published a number of pelvic diameters for 256 individuals of the same skeletal collection. In order to ascertain the obstetrical significance of the pubic length and the iliopectineal chord length we have calculated their correlation with three of Serra's pelvic inlet diameters

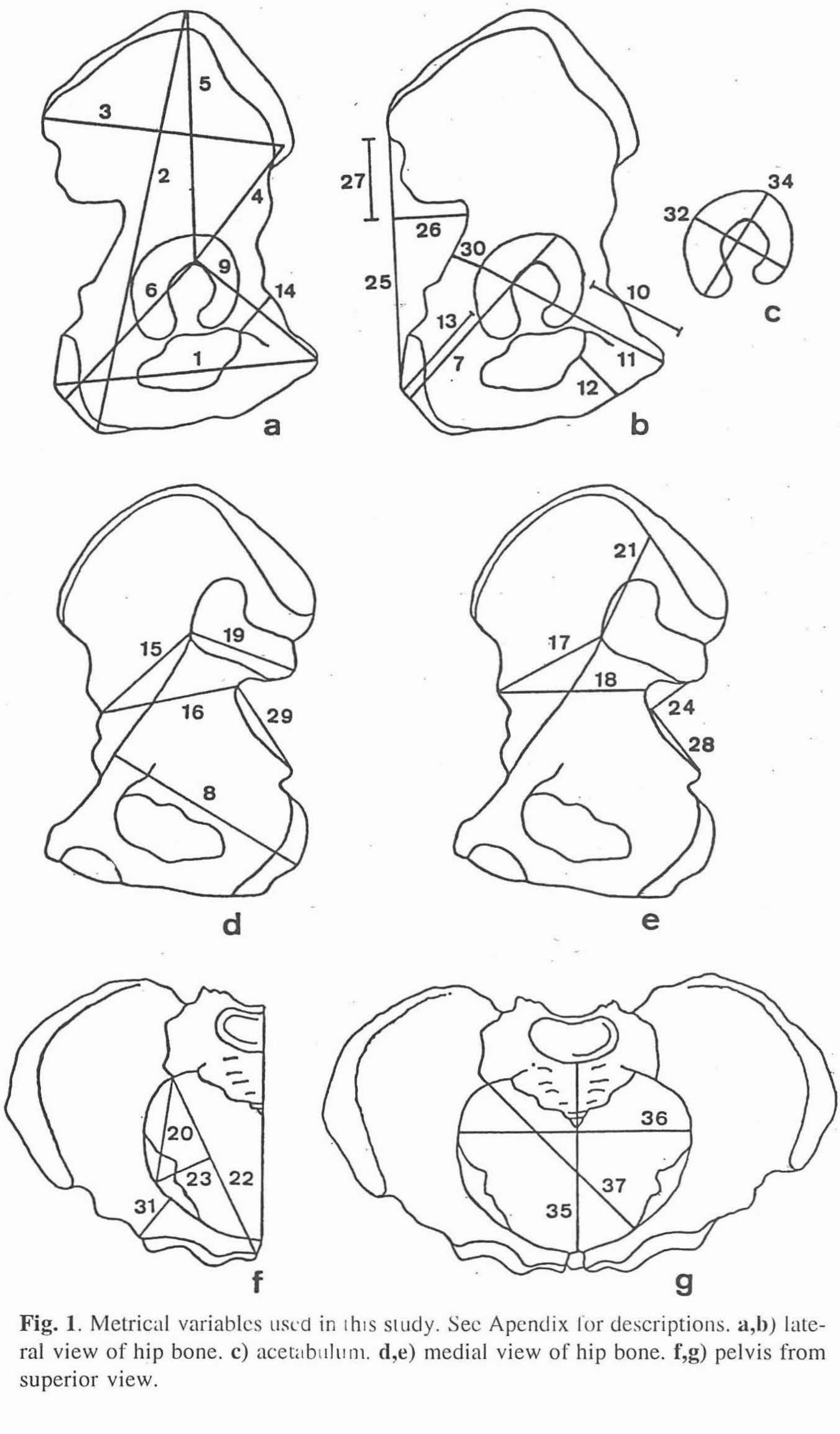

Fig. 1. Metrical variables used in this study. See Apendix for descriptions. **a,b**) lateral view of hip bone. **c**) acetabulum. **d,e**) medial view of hip bone. **f,g**) pelvis from superior view.

that we did not take (VAR35, VAR36 and VAR37, Table 1). To calculate the correlations between pelvic inlet variables and femur size (as a surrogate for overall body size) we also used our measurements of the maximum femoral length for 149 skeletons of the Coimbra collection.

Table 1. Correlation coefficients between six log raw variables for the Coimbra sample (M+F) = Males and females. (M) = Male subsample. (F) = Female subsample. Number in brackets = number of individuals. * = $p < 0.01$.

		VAR9 Pubic length									
VAR22	(M+F)	.60	(343)*	**VAR22**							
	(M)	.58	(183)*	**Iliopectineal**							
	(F)	.64	(160)*	**Line length**							
VAR35	(M+F)	.45	(206)*	.76	(204)*	**VAR35**					
	(M)	.34	(104)*	.68	(104)*	**Sagittal Inlet**					
	(F)	.54	(102)*	.78	(100)*						
VAR36	(M+F)	.46	(206)*	.46	(204)*	.31	(255)*	**VAR36**			
	(M)	.32	(104)*	.27	(104)*	.10	(125)	**Transverse inlet**			
	(F)	.57	(102)*	.46	(100)*	.28	(130)*				
VAR37	(M+F)	.50	(206)*	.56	(204)*	.39	(255)*	.86	(255)*	**VAR37**	
	(M)	.42	(104)*	.41	(104)*	.27	(125)*	.72	(125)*	**Diagonal Inlet**	
	(F)	.57	(102)*	.56	(100)*	.32	(130)*	.91	(130)*		
VAR38	(M+F)	.35	(129)*	.11	(126)	.03	(104)	.03	(104)	.10	(104)
Femur	(M)	.54	(67)*	.42	(66)*	.00	(51)	.33	(51)*	.35	(51)*
length	(F9)	.50	(62)*	.46	(60)*	.40	(53)*	.38	(53)*	.43	(53)*

We carried out a principal component analysis (P.C.A.) of the Coimbra raw data. Only complete cases were included in the computations (N=201). Variables 28 and 29 were excluded because of the great number of missing data. The remaining thirty two metrical variables were log transformed (for allometric correction) and standardized (by subtracting the mean and dividing by the standard deviation) before extracting principal components.

In order to remove the size factor from the data, each of the 32 variables was divided by the geometric mean of that case and then log transformed and standardized. Size is defined as the geometric mean of all variables and it is calculated as $(X_1{*}X_2{*}X_3...{*}X_{32})^{1/32}$ (Simons *et al.*, 1991). Then, a new principal component analysis (PCA) of these 'shape variables' was performed. The metrical data were analyzed using SPSS Version 3.1 (Norusis, 1990).

Finally, beside the metrical analysis of linear variables, we have recorded ten non-metrical (morphological) variables that have been claimed to be sexually dimorphic, each divided into three states (see Appendix).

Results and Discussion

Pelvic inlet variables and femur size

Mobb and Wood (1977) and Wood and Chamberlain (1986) state that sexual dimorphism in birth-canal-related dimensions in several primate species (including *Homo sapiens*), is not merely a consequence of body size dimorphism (*contra* Steudel, 1981). In the Coimbra human sample, pubic length shows similar correlation coefficients with the sagittal, transverse and diagonal diameters of the pelvic inlet, whereas iliopectineal chord length is more highly correlated with sagittal diameter ($r = 0.78$ in females, Table 1). When pubic length or iliopectineal chord length are regressed against femur length, the correlations estimated separately for each sex are greater than the correlations found in the pooled-sex sample (Table 1). When the pelvic inlet diameters are considered, the transverse and diagonal diameters are significantly correlated with the femur length in the male and female subsamples, but there are no significant correlations in the pooled-sex sample. Only in the females is the sagittal diameter significantly correlated with femur length (Table 1). These results indicate that the nature of the relationships between these pelvic inlet diameters and femoral length is different in males and females, and thus sexual dimorphism in body size is not the only important determinant of pelvic inlet sex differences.

Univariate analysis of sexual dimorphism in the Coimbra sample

The univariate analysis of the Coimbra raw data (Table 2) shows that the female averages are significantly greater than the male averages in the length and subtense of the iliopectineal chord, in the lower iliac height, supra-acetabular--auricular distance, non-articular pubic length, pubic body breadth and in two variables reflecting a broader sciatic notch. This pattern of sexual dimorphism is similar to that found by Genovés (1959) and Segebarth-Orban (1980) in other European modern populations. Nevertheless, Segebarth-Orban (1980) only compared raw data averages, and thus, sex differences in shape were not studied. For instance, she concludes that the length of the pubis and the width of the ischio-pubis are not significantly sex-dependant. When the raw variables are transformed to 'shape variables', the female averages are greater than the male averages in the above mentioned variables as well as in the pubic length, articular pubic length, anterior inferior spine-auricular distance, iliac breadth, ischio-pubic diameter and projection of the anterior superior spine (Table 2).

Table 2. Statistics of 34 innominate bone variables for the Coimbra sample. Italics indicates significant differences between sex averages (p < 0.01). In each case the larger value has been underlined.

	RAW DATA (mm)									TRANSFORMED VARIABLES					
	MALES				FEMALES					MALES			FEMALES		
	X	S.D.	n	C.V.	X	S.D.	n	C.V.		X	S.D.	n	X	S.D.	n
VAR1	*118.3*	5.6	186	4.7	116.6	6.1	161	5.2		.30	.01	118	*.30*	.02	83
VAR2	*211.9*	9.3	209	4.3	195.9	9.4	181	4.7		*.52*	.01	118	.51	.01	83
VAR3	*155.6*	7.9	193	5.0	152.9	7.9	164	5.1		.39	.01	118	*.40*	.01	83
VAR4	83.9	5.1	193	6.0	82.6	6.0	164	7.2	**	.12	.02	118	*.13*	.03	83
VAR5	*124.0*	6.2	209	5.0	118.7	6.7	175	5.6		*.30*	.01	118	.29	.01	83
VAR6	*94.5*	4.8	201	5.0	84.6	4.1	154	4.8		*.17*	.01	118	.14	.02	83
VAR7	*103.1*	4.7	214	4.5	92.2	4.3	184	4.6		*.21*	.01	118	.18	.01	83
VAR8	*96.7*	4.9	209	5.0	87.7	4.5	182	5.1		*.18*	.01	118	.16	.01	83
VAR9	86.4	5.6	188	6.4	87.9	5.8	166	6.5		.13	.02	118	*.15*	.02	83
VAR10	66.9	4.2	189	6.2	*69.5*	4.4	165	6.6		.02	.02	118	*.05*	.02	83
VAR11	115.5	5.6	188	4.8	113.9	6.1	165	5.3		.26	.01	118	*.27*	.01	83
VAR12	27.5	3.3	188	12.0	*30.9*	3.1	164	10.0	**	-.36	.05	118	*-.30*	.04	83
VAR13	*48.7*	3.1	214	6.3	43.1	2.9	184	6.7		*-.12*	.02	118	-.15	.02	83
VAR14	*15.3*	2.4	213	15.6	13.8	2.1	183	15.2		-.63	.06	118	-.64	.06	83
VAR15	68.2	5.0	221	7.3	*69.7*	6.1	185	8.7	**	.03	.02	118	*.05*	.03	83
VAR16	*60.8*	3.8	222	5.5	54.7	3.4	186	6.2	*	*-.02*	.02	118	-.05	.02	83
VAR17	71.8	5.2	214	7.2	72.3	6.0	184	8.2	*	.05	.02	118	*.07*	.03	83
VAR18	*70.3*	4.5	215	6.4	63.8	4.1	184	6.4		*.04*	.02	118	.02	.02	83
VAR19	*51.7*	4.5	212	8.7	48.0	4.7	177	9.7		-.09	.04	118	-.11	.04	83
VAR20	56.8	5.5	211	9.6	*61.1*	6.3	178	10.3		-.04	.04	118	*-.01*	.04	83
VAR21	*70.2*	5.0	210	7.1	62.3	5.7	176	9.1	**	*.04*	.03	118	.01	.03	83
VAR22	113.2	6.1	186	5.3	*119.0*	8.0	159	6.7	**	.25	.02	118	*.29*	.02	83
VAR23	22.2	2.7	186	12.1	*26.9*	3.5	159	13.0		-.45	.05	118	*-.37*	.05	83
VAR24	37.1	4.8	213	12.9	*41.3*	5.4	150	13.0		-.23	.06	118	*-.17*	.05	83
VAR25	129.6	9.3	197	7.1	127.4	8.3	166	6.5		.31	.02	118	.32	.02	83
VAR26	*43.7*	3.5	197	8.0	42.0	3.6	166	8.5		-.16	.03	118	-.16	.03	83
VAR27	56.5	5.8	197	10.2	*61.0*	5.9	166	9.6		-.05	.04	118	*.00*	.04	83
VAR28	28.7	5.2	165	18.1	30.0	4.2	115	14.0	**						
VAR29	*41.9*	3.5	164	8.3	39.5	3.3	115	8.3							
VAR30	*36.9*	3.1	218	8.4	33.3	2.8	187	8.4		*-.24*	.03	118	-.27	.02	83
VAR31	*26.7*	2.7	206	10.1	21.3	2.8	180	13.1	**	*-.37*	.04	118	-.46	.05	83
VAR32	*54.3*	3.0	207	5.5	49.0	2.8	181	5.7		*-.07*	.02	118	-.10	.01	83
VAR33	*25.1*	2.6	187	10.3	22.8	2.2	171	9.6		*-.41*	.03	118	-.43	.03	83
VAR35	*55.2*	2.8	213	5.0	49.9	2.7	184	5.4		*-.06*	.02	118	-.09	.02	83

X = mean. S.D. = standard deviation. C.V. = coefficient of variation. Asterisks = Significance of the one-tail Student's t-test comparing coefficients of variation between males and females: * Probability < 0.05, ** Probability < 0.01. Shape variables = in order to remove the size factor from the data, each variable was divided by the geometric mean of that case and then log transformed. Variables are: **Variable 1** = Maximum ischio-pubic diameter. **Variable 2** = Maximum coxal bone height. **Variable 3** = Maximum iliac breadth. **Variable 4** = Projection of the anterior superior iliac spine. **Variable 5** = Iliac height. **Variable 6** = Ischial length. **Variable 7** = Articular ischial length. **Variable 8** = True pelvis depth. **Variable 9** = Pubic length. **Variable 10** = Non-articular pubic length. **Variable 11** = Articular pubic length. **Variable 12** = Pubic body breadth. **Variable 13** = Non-articular ischial length. **Variable 14** = Pubic ramus depth. **Variable 15** = Supra-acetabular-auricular distance. **Variable 16** = Iliac minimum breadth. **Variable 17** = Anterior inferior iliac spine to the auricular surface. **Variable 18** = Anterior inferior iliac spine to the greater sciatic notch. **Variable 19** = Auricular length. **Variable 20** = Lower iliac height. **Variable 21** = Upper iliac height. **Variable 22** = Iliopectineal chord length. **Variable 23** = Iliopectineal chord subtense. **Variable 24** = Sciatic notch height. **Variable 25** = Length of the posterior border of the hip bone. **Variable 26** = Sciatic notch depth. **Variable 27** = Position of the deepest point of the sciatic notch. **Variable 28** = Distance from the lower end of the sciatic notch height to the base of the sciatic spine. **Variable 29** = Distance from the deepest point of the greater sciatic notch to the base of the sciatic spine. **Variable 30** = Cotylosciatic breadth. **Variable 31** = Cotylopubic breadth. **Variable 32** = Transverse acetabular diameter. **Variable 33** = Acetabular depth. **Variable 34** = Vertical acetabular diameter.

Multivariate analysis of log raw data in the Coimbra sample

The first component of the P.C.A. accounts for 40.3% of the total sample variance and clearly represents size variation. All the variables are positively correlated with this component, except the subtense of the iliopectineal chord. Moreover, the scores of the first component are highly correlated with hip bone size as expressed by the log geometric mean of all variables ($r=0.94$, $p< 0.001$).

The second component explains 18.4% of the total sample variance and is less correlated with the log geometric mean ($r=0.27$, $p<0.001$). Variables with positive loadings higher than 0.3 on this factor are those which express pubic length, length and subtense of the iliopectineal chord, the position of the auricular surface with respect to the anterior margin of the iliac bone and the acetabulum, the shape of the greater sciatic notch, and iliac width. Variables with negative loadings greater (in absolute value) than -0.3 are the acetabular diameters and the articular ischial length (Table 3). The second component is not a bipolar axis because the factor loadings distribution is clearly biased in favour of the positive loadings. Thus, this component is not a true shape axis, and this is why it only separates sexes when it is combined with multivariate size (first principal component). When the first principal component is plotted with the second one, two clusters of individuals arise, corresponding to the males and the females (Figure 2). As both clusters are obliquely oriented, neither of the first two components can be considered a "sexual" axis. Figure 2 shows that the female hip bone displays proportionately higher values for those variables associated with the pelvic inlet and greater sciatic notch (all of them of obstetric significance).

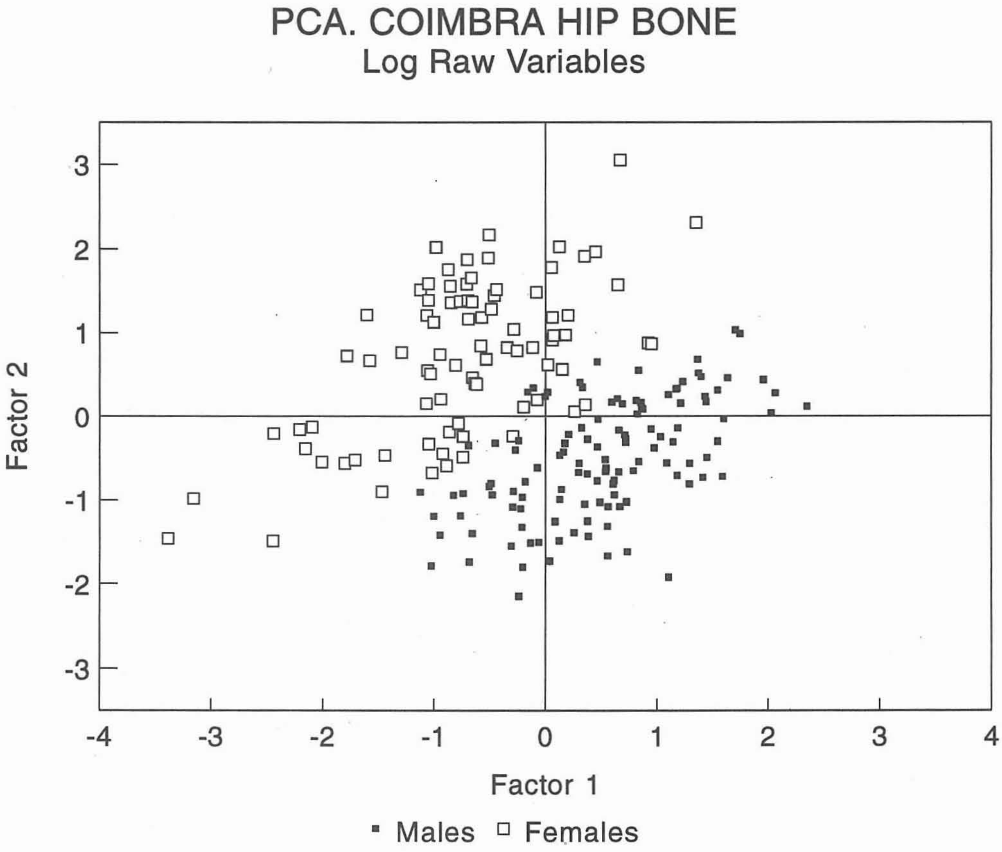

Fig. 2. First and second principal components of 32 log raw variables from the Coimbra modern human sample.

So, we agree with Mobb and Wood (1977) and Wood and Chamberlain (1986) in that human females exhibit differential hip bone growth in those dimensions that are related to the birth canal.

The third principal component accounts for 7.2% of the total sample variance. This component does not indicate sexual dimorphism but morpho-functional constraints related to overall pelvic inlet size. In both sexes, the hip bones with the sacroiliac joint and the anterior margin of the sciatic notch placed in a posterior position (with respect to the anterior iliac margin and the acetabulum) have short pubic bones (Table 3). Conversely, an elongated pubic bone is accompanied for by a more anterior position of the auricular surface and the sciatic notch with respect to the anterior iliac margin and the acetabulum.

Table 3. Principal Components Analysis of 32 log raw variables for the Coimbra sample. Only loadings higher in absolute value than 0.3 are printed. P.C. = principal component. Variables as in Table 2.

	LOG RAW VARIABLES		
Variables:	P.C.1	P.C.2	P.C.3
VAR2	.92		
VAR7	.87	-.33	
VAR8	.87		
VAR6	.86		
VAR32	.86		
VAR34	.82	-.30	
VAR5	.82		
VAR18	.80		
VAR16	.80		.30
VAR11	.80	.34	-.38
VAR13	.77		
VAR30	.77		
VAR21	.76		
VAR33	.73		
VAR3	.72	.38	
VAR1	.71		-.35
VAR31	.69	-.40	
VAR19	.53		
VAR4	.47		
VAR22		.83	
VAR23		.81	
VAR20		.76	.42
VAR15	.31	.70	.54
VAR17	.40	.66	.49
VAR27		.64	
VAR24		.61	
VAR10	.42	.58	-.56
VAR9	.47	.52	-.47
VAR12		.46	-.60
VAR25	.48	.38	
VAR26	.53		
VAR14	.36		

Multivariate analysis of 'shape variables' in the Coimbra sample

Once the effects of size have been removed (see above), the first principal component of the new PCA accounts for 32.9% of the total variance and neatly separates the male and female subsamples (Fig. 3). Almost all the males have positive scores and almost all the females have negative scores. The male coxal

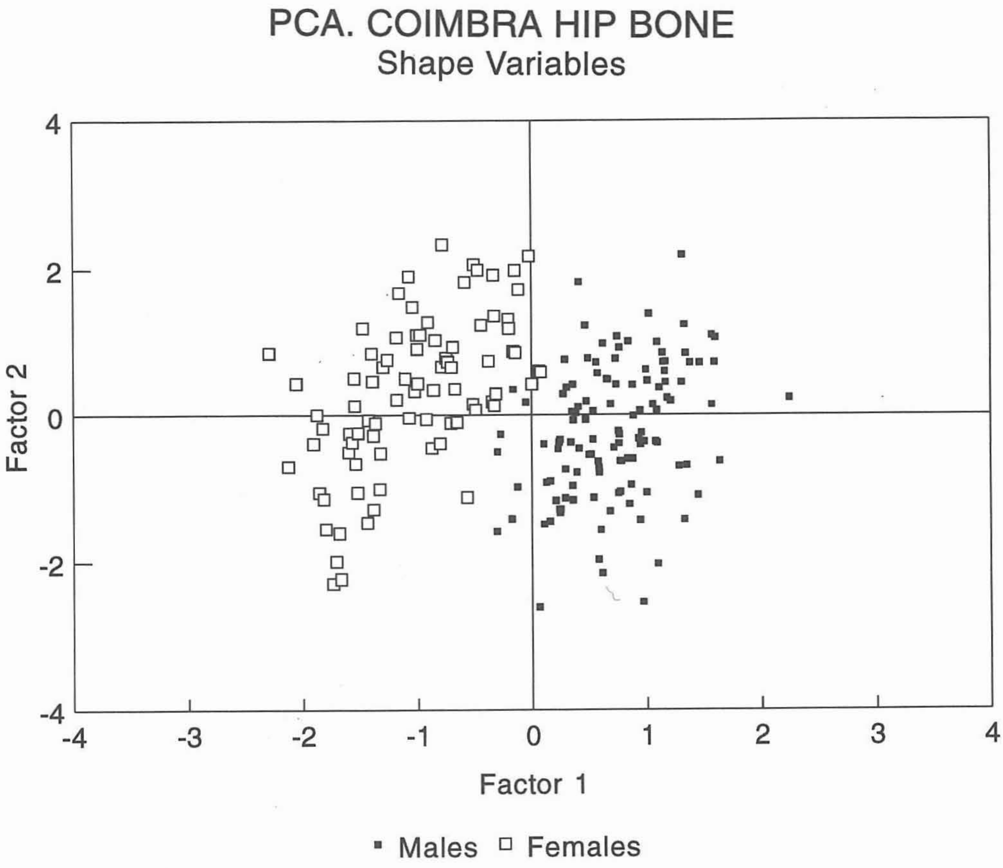

Fig. 3. First and second principal components of 32 shape variables from the Coimbra modern human sample.

bones display relatively larger and deeper hip joints, greater coxal height, greater ischial length, a deeper true pelvis, greater upper iliac height, a more posteriorly placed anterior margin of the greater sciatic notch (i.e., greater iliac minimum breadth), and a larger auricular surface. The female coxal bones show a greater length and subtense of the iliopectineal chord, a larger height of the sciatic notch and a position of the deepest point of the sciatic notch closer to the posterior superior iliac spine (i.e., a wider sciatic notch), a longer pubic bone and a more posterior position of the auricular surface with respect to the anterior iliac margin and the acetabulum (Table 4, Figure 3); all these traits are related to the pelvic inlet or to the shape of the greater sciatic notch, a trait of extraordinary obstetric relevance.

The second principal component accounts for 11.7% of the variance. The pattern of factor loadings is similar to that of the third component in the PCA on log raw data.

Table 4. Principal Components Analysis of 32 'shape variables' for the Coimbra sample. Only loadings higher in absolute value than 0.3 are printed. Variables as in Table 2.

	SHAPE VARIABLES	
Variables	P.C.1	P.C.2
VAR7	.87	
VAR23	-.81	
VAR6	.79	
VAR22	-.79	
VAR32	.79	
VAR8	.78	
VAR34	.74	
VAR31	.71	
VAR2	.70	
VAR13	.70	
VAR20	-.69	-.47
VAR24	-.65	
VAR21	.64	
VAR16	.62	-.38
VAR27	-.62	
VAR18	.57	
VAR30	.49	
VAR11		.79
VAR10	-.54	.66
VAR15	-.62	-.65
VAR17	-.57	-.62
VAR1		.62
VAR9	-.43	.60
VAR12	-.47	.49
VAR4		.32
VAR33	.43	
VAR19	.34	

Non-metrical analysis of sexual dimorphism in the Coimbra Sample

Most of the non-metrical variables (Figure 4) can be easily related to our metrical observations. The shape of the sciatic notch, for instance, is a good sex indicator. The composite arc reflects the position of the auricular surface relative to the anterior margin of the greater sciatic notch. We have not confirmed the high sexual dimorphism of this trait reported by Genovés (1959), but it is well--established that an auricular surface clearly posterior to the sciatic margin (character state 3) is a female feature. The shape of the obturator foramen is likely related to the relative lengths of the ischial and pubic bones, but it is not very useful in sexing hip bones. The angle of union of the medial surface of the ischio--pubic ramus and the pubic symphysis clearly reflects the acuteness or obtuseness of the subpubic angle, and is a very good sex indicator. There are marked sex differences of robustness in the medial aspect of the ischio-pubic ramus and the pubic crest. The subpubic concavity and the ventral arc occur with very high frequencies in the females of our sample, and almost never in the males. According to Budinoff and Tague (1990), the lateral placement of the ventral arc is positively correlated with the pubic length and, consequently, this trait should not be considered as an independent criterion from pubic length (but the reported correlation coefficient is only 0.39). Finally, we have investigated two types of bony grooves that are not supposed to be secondary sexual characters, but that only (or almost only) occur in females and have been associated with pregnancy and parturition. In the Coimbra sample, deep depressions in the dorsal aspect of the symphyseal region only appear in females, but with a low frequency. A well marked preauricular sulcus was found in most of the Coimbra females, and almost never in males. Unfortunately the number of deliveries is not recorded for the Coimbra females, but the distributions of the preauricular sulcus in married and non-married women were not found to be statistically different, although the sample of non-married women was of only 60 individuals (Arsuaga, 1985a).

By assigning the male sex to those specimens with the state 1 of the character and the female sex to the specimens with the state 3, predictive accuracies above 75% are obtained with the following non-metrical traits: preauricular sulcus, pubic crest robustness, pubic ventral arch, subpubic concavity, medial aspect of the ischio-pubic ramus and its angle of union with the pubic symphysis, and shape of the sciatic notch. Using this technique, in all the characters the directionality of the errors in sexing hip bones is contrary to that reported by Meindl et al. (1985). In the Coimbra sample it is more likely that females will be incorrectly sexed than will males using observational methods. Also, in all the characters, except in the medial aspect of the ischio-pubic ramus, there are more females than males with the state 2 (doubtful). On the other hand, there are no differences in sex prediction using metrical variables.

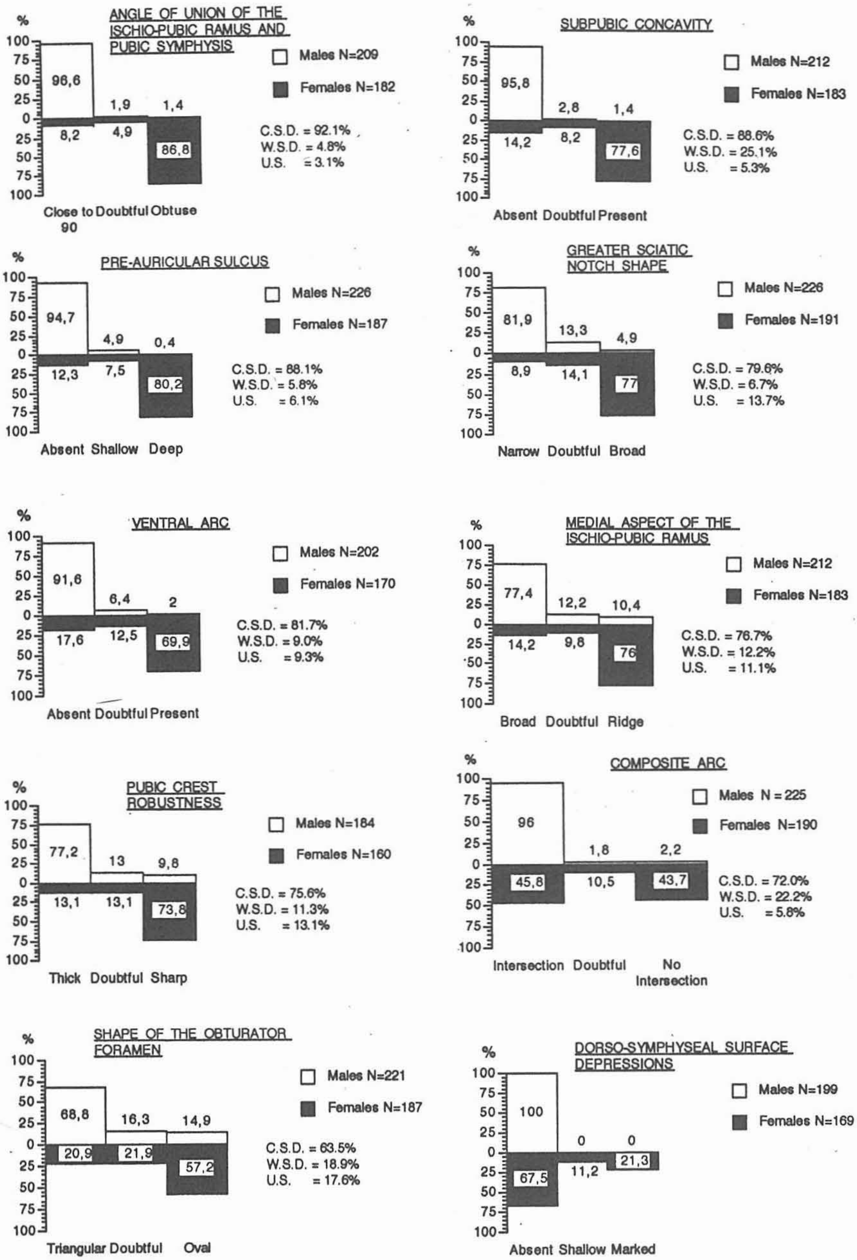

Fig. 4. Histograms of the nonmetrical traits for the Coimbra modern Human sample. See apendix for more details. Abreviatures: C.S.D. = Correct sex determination; W.S.D. = Wrong sex determination; U.S. = Unknown sex. An individual is sexe as a male when it shows the character state 1 (on the left) and as a female when it shows the character state 3 (on the right). An indivual is not assigned to any sex when it shows character state 2.

Discriminant analysis

We performed a stepwise discriminant analysis for our thirty four hip bone metrical variables (N=201). The discriminant function (which uses fourteen variables) correctly classified 98.6% of males and 100% of females. In spite of the sexual differences in the variability of visual cues of dimorphism, Tague (1989) found no sexual differences in the metrical variability of the pelvis. We have tested for homogeneity of coefficients of variation between males and females, for thirty four hip bone variables and three pelvic inlet diameters. Following Tague (1989), the coefficients of variation were corrected for bias and then the Student's one-tailed test (a = 0.05) was applied (Sokal and Braumann, 1980). Normality was tested for all variable distributions using K-S Lilliefors test, based on a modification of the Kolmogorov-Smirnov test (a = 0.05). In twenty seven variables the sexes do not differ in variability (Table 2). In eight variables the coefficients of variation were found to be significantly larger in females (VAR4, VAR15, VAR16, VAR17, VAR21, VAR22, VAR31, VAR37), although male distribution for VAR37 shows a significant departure from normality ($0.01 < p < 0.05$). Only in two variables were the coefficients of variation found to be significantly larger in males (VAR12 and VAR28). These sexual differences in hip bone variability could be due to environmental factors. It has been reported that variation in the size and shape of the pelvic inlet is partially the result of differences in nutrition during growth (Tague, 1992), and it is possible that this factor was more variable in the Coimbra females.

Variables with high correlations with the first component of the P.C.A of raw data can be used for sex determination. The acetabular diameters, the hip bone height, the true pelvis depth, the ischial length and the articular ischial length show correlation coefficients above 0.65 (and $p< 0.001$) with femur length, and thus largely express body size. A discriminant function for the two acetabular diameters determined the sex correctly in 83.9% of the cases (N=355), and a discriminant function for the articular ischial length alone succeeded in 89.2% of the cases (N=398) (Arsuaga, 1985a). Accuracy in sex prediction is improved with variables with high positive loadings on the second component. Discriminant functions for pubic length and ischial length (or articular ischial length and non--articular pubic length) show predictive accuracies around 94% (Arsuaga, 1985a,b; Arsuaga and Carretero, 1994). On the other hand, a discriminant function for three measurements related to the sciatic notch i.e., legth of the posterior border of the hip bone (VAR25), sciatic notch depth (VAR26), and position of the deepest point of the sciatic notch (VAR27), correctly classified 78.2% of the cases (N=362) (Arsuaga, 1985a). Genovés (1959) and Gaillard (1960) found marked sexual differences in the relations between the cotylopubic breadth (VAR31) and the minimum distances from the anterior inferior iliac spine to the auricular surface and the greater sciatic notch (VAR17 and VAR18). For these reasons, we calculated a discriminant function for VAR17, VAR18 and VAR31 that correctly classified 89.7% of the cases (N=378) (Arsuaga, 1985a).

Conclusions

The Principal Components Analysis on raw data in a large modern sample shows that a large amount of the hip bone sexual dimorphism is accounted for by size differences, but that sex-linked shape variation is also very conspicuous. On the other hand, the sexual dimorphism in the hip bone is not merely an allometric consequence of differences in body size between the sexes. The PCA on transformed 'shape variables' shows that males are relatively larger in the hip and sacroiliac joints, in the vertical diameters of the coxal bone, in the upper iliac height and in the iliac minimum breadth. The female hip bones are different in those traits associated with a relatively larger pelvic inlet (longer pubic bones, a greater degree of curvature of the iliopectineal line and a more posterior position of the auricular surface), as well as a broader sciatic notch.

Two of the non-metrical traits investigated are redundant with the metrical observations (shape of the greater sciatic notch and composite arc) and show the same pattern of sexual dimorphism associated with a broader sciatic notch and a lesser iliac minimum breadth in the females. Another trait of obstetrical significance (and very dimorphic) is the angle of union of the medial surface of the ischio-pubic ramus and the pubic symphysis. Two features reflect the more delicate structure of the female pubic bone (robustness of the ischio-pubic ramus medial surface and of the pubic crest). The ventral arch and the subpubic concavity are found in most of the females and very rarely in the males. Finally, there are very frequently depressions (related to ligament attachments) below the auricular surfaces of the female hip bones, and with low frequency in the dorsal aspect of the pubic symphysis. In the Coimbra collection the female hip bone is more variable than that of the male in the non-metrical traits, as well as in most of the metrical variables which show sexual differences in variability.

Acknowledgments

We are very grateful to Dr. Manuel Laranjeira Rodrigues de Areia and the staff of the Instituto de Antropologia of the Coimbra University for providing helpful access to the human skeletal collection in their care. We are also grateful to Dr. Robert Foley and the staff of the Department of Biological Anthropology of the University of Cambridge who offered their hospitality to one of us (J.L.A.) and assistance with the processing of the data.

This research was partially funded by the Dirección General de Investigación Científica y Técnica of Spain (Programa de perfeccionamiento y movilidad del personal investigador, PB90-0126-C03-02 y PB93-0066-C03-01) and by the Ministerio de Educación y Ciencia (Programa Sectorial de Formacion de Personal Investigador, Subprograma General en el Extranjero).

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Appendix

Definitions of metrical and non-metrical variables used in the analysis

Metrical Variables

Variable 1. *Maximum ischio-pubic diameter.*

Variable 2. *Maximum coxal bone height.*

Variable 3. *Maximum iliac breadth.* This diameter defines the landmarks for the anterior superior and posterior superior iliac spines.

Variable 4. *Projection of the anterior superior iliac spine.* From the acetabular point to the anterior superior iliac spine. The acetabular point is the nearest point to the anterior superior iliac spine on the inner margin of the lunate surface.

Variable 5. *Iliac height.* From the acetabular point to the most distant point on the iliac crest.

Variable 6. *Ischial length.* From the acetabular point to the most distant point in the tuberosity of the ischium.

Variable 7. *Articular ischial length.* The rectilinear distance from the point where the axis of the body of the ischium crosses the surface of the ischial tuberosity to the most distant point on the acetabular rim.

Variable 8. *True pelvis depth.* The maximum normal distance from the iliopectineal line to the tuberosity of the ischium.

Variable 9. *Pubic length.* From the acetabular point to the most medial point on the superior region of the pubic symphysis.

Variable 10. *Non-articular pubic length.* The minimum distance from the most medial point on the superior region of the pubic symphysis to the acetabular rim.

Variable 11. *Articular pubic length.* From the most medial point on the superior region of the pubic symphysis to the most distant point on the acetabular rim.

Variable 12. *Pubic body breadth.* From the middle point on the ventral margin of the pubic symphysis to the nearest point on the medial margin of the obturator foramen.

Variable 13. *Non-articular ischial length.* The distance between the points where the axis of the body of the ischium crosses the surface of the ischial tuberosity and the acetabular rim.

Variable 14. *Pubic ramus depth.* The cranio-caudal depth of the pubic ramus measured where the pubis crosses the groove for the obturator nerve.

Variable 15. *Supra-acetabular-auricular distance.* From the supra-acetabular point to the ilio-auricular point. The supra-acetabular point is the deepest point between the lower margin of the anterior inferior iliac spine and the adjacent margin of the acetabulum (McCown and Keith, 1939). The ilio-auricular point is the nearest point to the supra-acetabular point on the anterior margin of the auricular surface.

Variable 16. *Iliac minimum breadth.* From the supra-acetabular point to the nearest point on the greater sciatic notch.

Variable 17. *Anterior inferior iliac spine to the auricular surface.* Distance between the anterior inferior iliac spine and the closest point on the auricular surface.

Variable 18. *Anterior inferior iliac spine to the greater sciatic notch.* From the anterior inferior iliac spine to the nearest point on the greater sciatic notch.

Variable 19. *Auricular length.* From the ilio-auricular point to the most posterior point of the auricular surface.

Variable 20. *Lower iliac height.* Straus (1927) defined the lower iliac height as the distance from the auricular surface to the ilio-pubic junction on the iliopectineal line. Since the latter point cannot be accurately determined in adult hip bones, we use the nearest point on the iliopectineal line to the acetabular rim.

Variable 21. *Upper iliac height.* From the ilio-auricular point to the point where the anterior margin of the sacral surface meets the iliac crest.

Variable 22. *Iliopectineal chord length.* From the ilio-auricular point to the pubic terminal of the maximum ischio-pubic diameter.

Variable 23. *Iliopectineal chord subtense.* The maximum normal distance from the iliopectineal chord to the variable 22.

Variable 24. *Sciatic notch height.* The normal distance from the point where the superior margin of the greater sciatic notch meets the auricular surface, to the greater sciatic notch.

Variable 25. *Length of the posterior border of the hip bone.* The distance between the lowest point of the posterior superior iliac spine and the most medial point on the inside ridge of the sciatic tubercle.

Variable 26. *Sciatic notch depth.* The normal distance from the variable 25 line to the deepest point of the greater sciatic notch.

Variable 27. *Position of the deepest point of the sciatic notch.* The distance between the posterior superior iliac spine and the point at which the 'Sciatic notch depth' cuts the variable 25 line.

Variable 28. *Distance from the lower end of the sciatic notch height to the base of the sciatic spine*

Variable 29. *Distance from the deepest point of the greater sciatic notch to the base of the sciatic spine*

Variable 30. *Cotylosciatic breadth.* Minimum distance between the ilio-pubic notch on the acetabular rim and the sciatic notch.

Variable 31. *Cotylopubic breadth.* The normal distance from the pubic eminence on the acetabular rim to the iliopectineal line.

Variable 32. *Transverse acetabular diameter.* Maximum acetabular diameter from the pubic eminence on the acetabular rim.

Variable 33. *Acetabular depth.* Maximum depth of the acetabulum from the 'transverse' line.

Variable 34. *Vertical acetabular diameter.* Maximum acetabular diameter from the point where the axis of the ischial body intersects the acetabular rim.

Variable 35. *Sagittal inlet.* Distance between the superior point on the pubic symphysis and the sacral promontory.

Variable 36. *Maximum transverse inlet.* Maximum transverse distance between the ileopectineal lines.

Variable 37. *Diagonal inlet.* Distance between the ilio-auricular point and the point where the iliopectineal eminence meets the iliopectineal line on the opposite side.

Variable 38. *Maximum femoral length*

Non-Metrical Variables

Pre-auricular sulcus (groove between the inferior auricular margin and the sciatic notch): 1= No groove. 2= Shallow groove with not well defined border. 3= Deep and wide groove with a sharp border.

Depressions or cavities close to the dorsal margin of the symphyseal surface: 1= No depressions. 2= Shallow depressions. 3= Well defined depressions or cavities.

Greater sciatic notch: 1= Narrow notch. 2=Doubtful. 3=Broad notch.

Composite arc: 1= The line prolonging downward the anterior margin of the auricular surface intersects the anterior margin of the sciatic notch or its prolongation. 2=Doubtful. 3= The line prolonging the anterior margin of the auricular surface does not intersect the anterior margin of the greater sciatic notch.

Robustness of the pubic crest: 1= Thick, robust and round bar. 2= Doubtful. 3= Sharp crest.

Ventral arc: 1=Absent. 2= Doubtful. 3=Present.

Subpubic concavity: 1=Absent. 2= Doubtful. 3=Present.

Medial aspect of the ischio-pubic ramus: 1= Broad flat surface. 2= Doubtful. 3= Ridge.

Angle of union of the medial surface of the ischio-pubic ramus and the pubic symphysis: 1= Very obtuse angle; the lower limit of the symphyseal surface and the medial surface of the ischio-pubic ramus are not clearly separated. 2= Doubtful. 3= more acute angle close to 90°; the lower limit of the symphyseal surface is well defined.

Shape of the obturator foramen: 1= Triangular. 2= Doubtful. 3= Oval.

In the definitions of the variables we have followed Genovés (1959) (VAR1, VAR2, VAR3, VAR4, VAR5, VAR6, VAR9, VAR10, VAR11, VAR12, VAR15, VAR16, VAR19, VAR22, Composite arc and Angle of union of the medial surface of the ischio--pubic ramus and the pubic symphysis), Novotny (1986) (VAR7), McCown and Keith (1939) (VAR14), Gaillard (1960) (VAR17, VAR18, VAR31), Sauter and Privat (1954--55) (VAR24, VAR30), Jovanovic and Zivanovic (1965) (VAR25, VAR26, VAR27), Phenice (1969) (Ventral arc, Subpubic concavity and Medial aspect of the ischio-pubic ramus), and Serra (1938) (VAR35, VAR36, VAR37). For more extensive descriptions and comments on these and other similar variables see Arsuaga (1985a).