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Metric characterization of the human coxal bone on a recent Italian sample and multivariate discriminant analysis to determine sex.

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Abstract: The ability of human pelvic bones to sexually differentiate has been of great interest in forensic anthropology for quite some time as it allows for the determination of skeletal sex by combining metric and morphological data. However, the criteria for determining the sex of a skeleton must be calibrated according to the variability of the population to which it belongs. The aim of this work is the metric characterization of the human coxal bone on a recent sample (of known sex) from the region of Apulia, in southern Italy, in order to establish its efficacy in sex determination by way of multivariate discriminant analysis. Seventeen standard anthropological measurements used in sex determination were taken from 168 coxal bones (78 male, and 90 female) all belonging to 86 adult skeletons (40 males and 46 females). The bones used were taken from subjects who had died in the 1960s and 1970s in Apulia.

The results obtained define the variability in size and proportion of the sample analyzed with respect to the variations of other skeletal populations. Nine discriminant functions, utilizing between 4 and 11 variables, have been shown to be useful in determining the sex of coxal bones, whether they be complete, partial, or fragmented. All of the functions selected resulted in an attribution error equal to zero, and differ only in the number of variables utilized and by the degree of separation between the groups.

The results of this study confirm the validity and utility of diagnostic techniques based on discriminant functions as reported in the literature for other population groups. The combination of metric characteristics from various regions of the coxal bone is, therefore, a valid aid in the correct attribution of skeletal sex even when the combination of variables is numerically limited, but sufficient in sex determination from partial coxal bones.

Keywords:
Forensic anthropology population data;
Sex determination;
Coxal bone;
Multivariate discriminant analysis;
Southern Italy.

1. **Introduction**

The human pelvis is a morpho-functional complex whose shape is determined by factors related to evolution, biology, and specific population. This represents an integrated response by natural selection to the various forces that determine the shape of the structure: adaptation to standing position; bipedalism; and the need to give birth to offspring with ever increasing cranial diameters. All of these elements have repercussions on the biomechanical efficiency of the pelvis [1, 2].

These factors impose certain restrictions on the various regions of the pelvis in a number of ways. The sacroiliac segment, for example, is highly conditioned by the biomechanical demands resulting from erect body position and bipedalism, whereas the ischiopubic segment is mainly involved in the modifications caused by the differentiated reproductive needs of the two sexes [3]. In spite of their specific restrictions, the two segments of the pelvis modify their morphological expression according to their physiological limits as a way to safeguard the overall functionality of the pelvis. Furthermore, normal variability of sexual characteristics is also dependent upon individual factors such as size and age, and is differentiated according to the specific population.

With regard to quantitative techniques, metric evaluation and multivariate discriminant analysis remain the quickest and most efficient methods for determining differentiated sexual characteristics, especially in cases of complex structures such as the pelvis [4].

Following its first applications in determining skeletal sex, multivariate analysis came into common use in forensic anthropology [5-8]. Various authors report discriminant functions derived from sexual dimorphism studies on different populations, many of which regard the pelvis[5, 9-24].

Steyn and İşcan [25], Steyn and Patriquin [26], Robledo and colleagues [27], Yoldi-Chaure and Botella-López [28], Yoldi and colleagues [29], Rissech and colleagues [30], Arsuaga and Carretero [31] have all reported metric data on populations from the Mediterranean area. Murail et al. [32] studied world variability of sexual dimorphism on a large sample of coxal bones.

Our study analyzes the metric characterization of the human coxal bone on a recent sample (of known sex) from the region of Apulia in southern Italy with the aim of determining sex by means of discriminant multivariate analysis.

2. Materials and Methods

Eighty-six preserved adult skeletons (40 male and 46 female), for a total of 168 isolated coxal bones (78 male and 90 female), were taken from a collection of skeletons at the "Istituto di Medicina Legale", University of Bari (Italy) for this study. The skeletons had been the subjects of previous studies on sexual dimorphism [33-45]. The remains belonged to subjects who died in the 1960s and 1970s, and whose ages ranged from 24 - 92 years. Those subjects exhibiting evidence of pathologies or malformations were excluded from the study.

Seventeen measurements were taken that are traditionally reported in the literature regarding skeletal sex determination (Tab. 1). These values, measured in millimeters, were recorded to the first decimal place. Some measurements, which were either redundant, or taken using different standards, were equally considered in order to allow comparisons with analogous measurements reported in other studies. Systat software [46-47] was used to carry out the statistical analysis, where only primary data, and not indices, were used.

After measuring the parameters of the entire sample, 30 cases, selected randomly from all subjects included in the study, were measured by the same operator a second time (both coxal bones if present) after an interval of at least three-months from the time of the first measurements. The two series were then used to calculate intra-observer technical error of measurement (TEM) according to Lewis [48], Adão Perini et al. [49], and Ulijaszek and Kerr [50]. Lewis (*ibid.*) reports examples of TEM application on bone samples.

The number of elements that were measured twice was never less than 29% of measurable cases (e.g. PUM measurements were re-measured in 32 out of 111 cases). The TEM evaluators provided the intra-observer error estimates, which are expressed in their original unit of measure. The reliability coefficient (R) provided this value independent of the original unit of measure, which falls between 1 and 0. The R coefficient expresses the proportion of the "between-subject" variance free of measurement errors. For example, R = 0.95 indicating that 95% of the variance is due to factors not correlated to measurement errors. Generally, intra-observer error measurement is the result of the detection of landmarks.

The extent of the differences between the two series of measurements, which were recorded at two different times, was also evaluated using a paired sample t-test. Following this, the extent of natural asymmetries between left and right coxal bones was assessed. Because no significant differences between the two sides were observed, all of the data were pooled.

Normal distribution was evaluated using the Kolmogorov-Smirnov test (Lillierfors test), and the F-test was used to evaluate equality of variance. Descriptive statistics were then obtained for the male and female groups in order to characterize them metrically. For each variable, a comparison between the means of the two groups, using a two-sample t-test, was carried out.

Both stepwise and direct discriminant analyses were performed in order to define any functions that might be useful in the determination of skeletal sex. In the second case, the variables are included in the model, regardless of whether they meet the criteria for entry into the model. The functions were first independently selected by looking for the highest discrimination between the two groups independent of the number of variables used. Following this, functions based on a limited number of variables that were able to discriminate between the two groups were defined. Some of these variables were obtained from different anatomical regions of the coxal bone that might be used in cases involving incomplete skeletal remains.

Considering the small sample size, it was not possible to use a training set and a test set. Nevertheless, for an unbiased error estimate, the leave-one-out method was applied (cross validation is obtained by removing and reclassifying one case at a time from the entire sample), calculating the normal attribution error and jackknifed error [47, 51].

3. **Results**

The parameters for evaluation of intra-observer Technical Error of Measurements (TEM) are reported in Table 2. Low TEM values, (and relative TEM values with a maximum score for M21-OFB = 1.6%), and R-values that are consistently higher than 0.95, indicate an acceptable level of error and a reliable measurement. In addition, based on paired t-test results, the two series of repeated measurements do not differ significantly.

The paired t-Test result, used to evaluate the presence of asymmetries between the right and left coxal bones from the same pelvis when present, is reported in Table 3. The mean differences were not significantly greater than zero: values ranged from between 0.036 (PUM), and 0.402 (M17a-PUA). This demonstrates that the two series do not differ significantly. Because no significant differences were observed in any of the measurements, the data from both sides were pooled.

The results for the Kolmogorov-Smirnov test for the male and female groups are reported in Table 4. In the same table the results for homogeneity of variance test are also reported. In spite of the resulting probability values in some cases, they are close to the threshold of significance (0.05), the normal distribution hypothesis may not be excluded for any of the variables analyzed. So, even though the probability value assigned from the F test is close to the threshold of significance in some cases, the variance may generally be assumed to be equal, or not too dissimilar.

3.1. Descriptive statistics

Descriptive statistics for the male and female groups are reported in Table 5. The comparison between the sexes for each measurement recorded using t-Tests is reported in Table 6. In general, the measurements obtained for the male group are greater than those obtained for the female group, with some exceptions (PUM and M17a-PUA, pubis lengths; SA, spino-auricular length). In particular, values related to overall male coxal bone height (MO1-DCOX), ischial portion height (M15-ISL; ISM; M15a-ISA; and ISMM); acetabulum height (M22-VEAC); obturator foramen height (M20-OFL); and spino-sciatic length (SS) are higher. In addition, values related to bone robustness, such as cotylo-sciatic breadth (M14.1-SIS), and cotylo-pubic breadth (SPU), are higher in the male group. When considering iliac breadth (M12-SCOX), acetabular symphyseal breadth (M14-PUB), and obturator foramen breadth (M21-OFB), the differences are less evident.

The variables that have higher values in the female group, however, are incisura ischiadica major height (M15.1-IIMT); pubis length, both in the modified version according to Novotny, and the acetabular version according to Schultz (PUM and M17a-PUA respectively); and spino-auricular length (SA). The values related to overall bone height, and those concerning various partial segments were found to be highly significant. The values regarding bone “robustness”, namely cotylo-sciatic breadth (M14.1-SIS), and cotylo-pubic breadth (SPU) also resulted as highly significant.

Among the values concerning the breadth of various bone segments, acetabular-symphyseal breadth (M14-PUB**) results as highly significant; iliac breadth (M12-SCOX*) as significant; and obturator foramen breadth (M21-OFB) as not significant.

With reference to the variables in the female group with the highest values, the differences regarding incisura ischiadica major height result as highly significant (15.1-IIMT**). Those related to the spino-auricular length (SA*) result as significant. And those regarding pubis length measured from the acetabular point (M17a-PUA), resulted as not significant.

3.2. Multivariate Discriminant Analysis

Discriminant analysis results are reported in Tables 7 and 8. The non-standardized coefficients of the functions selected, the centroids for the male and female group scores, the sectioning points, and the related statistical evaluators are reported in Table 7. For all of the functions reported, the attribution error obtained (Jackknifed) was equal to zero for both groups, and so they differ only in the number of variables utilized, and in the degree of separation between groups.

The weight of each variable in the functions is given by the standardized canonical discriminant coefficients reported in Table 8.

Function No. 1 consists of a combination of 11 variables, which have fewer attribution errors, and best separate the two groups. These variables were selected using the backward-stepwise method (F-to-enter 4.0, F-to-remove 3.9). These variables are related to the following: overall bone height (M01-DCOX); ischial portion (M15a-ISA); the acetabulum (M22-VEAC); obturator foramen (M21-OFB); iliac breadth (M12-SCOX); acetabular-symphyseal breadth (M14-PUB), as well as cotylo-sciatic, and cotylo-pubic breadths (M14.1-SIS and SPU). The incisura ischiadica major height (M15.1-IIMT) and the measurements evaluating the relationships between the sciatic notch and the auricular border (i.e. the spino-sciatic: SS; and spino-auricular lengths: SA), were also selected. Some of the variables considered show a certain degree of correlation, particularly those concerning the ischium. Although some of these allow evaluation of proportionality between the various bone segments to be made according to height, others are redundant. As stated earlier, these variables have been reported in order to render it possible to make a comparison between other studies where these variables were used. In general, the measurements related to bone height (M01-DCOX, M22-VEAC, ISM and M15a-ISA, ISMM) show a correlation. Among the various bone height measurements, coxal bone height (M01-DCOX) shows a correlation variable degree of between 0.783 (Pearson corr. coeff.) for acetabulum height (M22-VEAC), and 0.899 for post-acetabular ischium length (ISMM). The measurements regarding the pubis, following the techniques of Novotny, and of Schulz (PUM and M17a-PUA), along with the M14-PUB measurements for the pubis (acetabulum included) also show a correlation.

In Function No.1, obtained through stepwise discriminant analysis, some of the redundant variables for the ischium (ISM, ISMM), and the pubis (PUM and M17a-PUA) were excluded. The degree of correlation, in addition to the F value, was also considered in the identification of subsequent functions (reported in Table 7) as general criteria for the inclusion or exclusion of variables. Function No. 1b is a variant in which the measurement for the ischium, as defined by Schulz [54] (M17a-PUA), was substituted with the modified one according to Novotny [12] (ISM) in order to overcome the problems in identifying the acetabular point.

Function No. 2 was obtained using a set of variables very similar to that recommended by Murail and colleagues [32]. According to the authors, the function is obtained "*from a very large reference sample of hip-bones from four continents*". Applied to our population, the function obtained separates the two groups without error, and with a slightly lower degree of separation with respect to Function No. 1. As a matter of fact, the inclusion of post-acetabular ischium length (ISSM) in our study may be considered negligible. Its inclusion or exclusion in the function does not result in substantial error variations, nor does it affect the distance between centroids. We have, however, maintained the complete series of 10 variables in order to render it possible to make comparisons with Maurail and colleagues' study.

After having obtained Function No. 1, further combinations of variables were selected with the aim of facilitating the application of these functions by decreasing the number of variables, thereby maintaining an acceptable level of discrimination and separation between the groups.

The first step toward this objective involved progressively eliminating variables with lower F values until a combination of 8 variables was reached. Functions No. 3 and No. 4, which are based on eight variables, differ in how ischium length (ISM) and acetabular height (M22-VEAC) are utilized. The two functions also maintain a distance value between the male and female groups comparable to those obtained for Functions No. 1 and No. 2. The functions described thus far are only applicable in cases of reasonably complete coxal bones.

We then tried to verify if it were possible to identify combinations of variables related to measurements taken from localized morphological areas that are both numerically limited (4 variables) and efficient in identifying groups in the examination of partial or fragmented coxal bones.

Measurements taken from coxal bones that were conserved mainly from the ischio-pubic area were used in Function No. 5: incisura ischiadica major height (M15-IIMT); pubis and ischium lengths, according to Novotny (PUM and ISM); and post-acetabular ischium length (ISMM).

Function No. 6 utilizes variables detectable on the coxal bone with missing or eroded symphyses, as is often the case, but where part of the pubic ramus is conserved: incisura ischiadica major height (M15-IIMT); cotylo-pubic breadth (SPU); and measurements regarding the relationships between the incisura ischiadica major and the auricular surface (SS and SA).

In Function No. 7, measurements taken from the coxal bone were used where the best preserved area was the ischium: incisura ischiadica major height (M15-IIMT); ischium length, modified according to Novotny (ISM); and the measurements regarding the relationships between the incisura ischiadica major and the auricular surface (SS, SA).

And finally, variables related to the coxal bone, where the ilial and ischial areas were preserved, were utilized in Function No. 8: coxal bone height (M01-DCOX); iliac breadth (M12-SCOX); and the measurements involving the relationships between the incisura ischiadica major and the auricular surface (SS, SA).

For all of the functions, the canonical scores of group means (csgm) was higher in the male group, with the exception of Functions No. 5, 6 and 7, where the highest absolute canonical scores of group means was in the female group: this is due to the fact that these mostly regard measurements of the pubic bone and sciatic notch.

Some variables (M15-ISL - ischium length; M17a-PUA - pubis length; and M20-OFL - obturator foramen breadth) were never selected for the functions reported.

Discussion and conclusions

One consideration must be made regarding the results obtained by means of evaluating the asymmetries between the right and left coxal bones (Tab. 3). Despite the fact that asymmetries were not significantly different, the maximum differences obtained for M17a-PUA may be due to difficulty in detecting the acetabular point as described by various authors [3], and not due to asymmetry between the left and right components. This suggests that more careful attention is needed when ischio-pubic data are used when evaluating sex according to the Washburn technique.

With regard to descriptive statistics (Tab. 5), the range detected for each measurement taken (i.e. those measurements common to both studies) falls within the range reported by Murail and colleagues for twelve world populations [32]. The greatest differences found between the sexes that are ascribable to differences in size and proportion, are mostly found in bone height.

Some of the contrasting elements, such as the difference in significance of pubis bone length according to Novotny, and also according to Schulz, should be reconsidered. Schulz's technique for measuring pubis length, which resulted as not significant, brings with it a certain margin for uncertainty due to the difficulty in accurately identifying the acetabular point as stated above. But this uncertainty should also apply when measuring the height of the ischium using the same technique, which resulted as highly significant. It is possible that when considering ischial height, the errors that resulted from the uncertain measurement of the acetabular point were hidden by the greater and more evident differences between the male and female groups. Because of these greater differences, measurements of the ischium are less influenced by any inaccuracies in determining the acetabular point.

The difficulty in determining skeletal sex lies in the need to reduce the quasi-continuous variations of morphological features into a discrete classification according to the subject's genetic sex [3, 57]. In practice, a certain level of overlapping of sexual characteristics related to size, shape, and proportion is always seen. Ontogenesis and the population to which a subject belongs also influence phenotypical expression of genetic sex in all parts of the skeleton [18], including the pelvis, despite it being the most sexually differentiated part.

The results obtained from this study highlight two principal points. The first regards the metric characterization of the sample analyzed in order to define general variability and degree of sexual differentiation. Although information regarding variability is available for a number of populations, no general criteria currently exist that safely allow for the transfer of diagnostic elements from one population to another. For this reason, the metric characterization of a sample of known origin is essential for establishing reliable diagnostic criteria. This is confirmed if we consider, for example, the ischiopubic proportions of the population analyzed in this study with respect to other human population groups. The ischiopubic index calculated for this sample is equal to 89.2 for males (N = 53, SD = 5.7), and 100.0 for females (N = 58, SD = 4.8). On a sample of "European-Americans", Washburn reports a value from the same index equal to 83.6 (N = 100, SD = 4.0) for the male group, and 99.5 (N = 100, SD = 5.1) for the female group. And on a sample of "African-Americans", the index values obtained for the male group is equal to 79.9 (N = 50, SD = 4.0), and 95.5 (N = 50, SD = 4.6) for the female group. It is evident that the proportion values obtained are different in the groups compared.

If we compare Novotny's ischiopubic index [58] when applied to a series of central European pelvises dating from the second half of the nineteenth century, and into the twentieth century, the average value reported for the male group is equal to 64.6 (N = 115, SD = 3.7), whereas the female group is equal to 76.9 (N = 117, SD 3.5). For the sample analyzed in our study, the index value obtained using Novotny's technique on the male group is equal to 64.6 (N = 53, SD = 2.5) and 75.6 (N = 58, SD = 5.2) for the female group. As a result, the proportional characteristics of the two groups, as expressed using this index, appear to be almost superimposable.

The characterization of a population is, therefore, necessary for defining specific regional criteria. It is also necessary in order to highlight common ranges of variability, thereby making it possible to confidently apply general diagnostic criteria.

The second important point revealed by the results obtained regard the efficacy of the functions derived from multivariate discriminant analysis. For all of the functions selected, both for those with a relatively high number of variables (functions 1-6, based on 8, 10 and 11 variables), and those with a limited number (functions 7-10, based on 4 variables), the attribution error obtained was equal to zero in the male and female groups. This result is significant when compared to results obtained from the same sample using various types of analysis (morphological and metric), and on different skeletal areas. The same sample was, in fact, studied for sexual dimorphism, using morphological characteristics of the skull and pelvis that resulted in a corrected attribution equal to 92.05% [33]. The corrected attribution for metric characteristics of the skull [35] is equal to 93.75%, and between 83% and 95% when considering metric elements of the post-cranial skeleton [36-45].

The results obtained are satisfactory, even when compared to some of the discriminant functions typically reported in the literature on the coxal bone. Ferembach et al. [14] reported discriminant functions for sex determination, as defined by Novotny, that were based on coxal bone metric characteristics whose corrected attribution range varied between 88.4% and 100%, utilizing two to four variables. Bruzek and Murail [59] also report one of the functions (Function No. 4: 100% corrected attribution based on four variables), along with other functions that, according to the authors, "*have been shown to be reliable after tested on several independent samples"*. Two of these equations are based on three and four variables and allow for a corrected attribution percentage greater than 95%. An additional function, defined by Schulter-Ellis et al. [16], is based on two variables, one of which is an index that gives an attribution percentage equal to 98%.

Among the functions reported in forensic literature, those determined by Gilles [10] for the coxal bone use combinations of variables that recur in the functions selected in our study. Two of the variables used (i.e. ischial and pubic length) show a proportionality between the ischium and the pubis; one regards the depth of the incisura ischiadica major height; two are measurements of “robustness” (acetabular-sciatic and pubic breadth); and one measurement, which results from the difference between the spino-auricular length and the spino-sciatic length, assesses the position of the incisura ischiadica major and the auricular surface. Gilles’ two functions, based on four and six variables, provide a correct attribution percentage of 93.1% and 96.5%, respectively.

The standardized coefficients for the selected variables are reported in Table 8; they allow for direct evaluation of the weight that every variable assumes in the functions. The contribution each one makes obviously varies in relation to the combination of variables. However, if we consider their presence in the functions, it turns out that some of these are never selected (M15-ISL, M17a-PUA, M20-OFL9), and others (15.1-IIMT, SPU, SS, SA) are consistently selected, except for those with four variables, in which case inclusion or exclusion occurs manually in order to identify effective combinations of variables useful in the separation of groups and applicable in cases where remains are damaged or incomplete.

In conclusion, the results we have obtained do not contradict Novotny’s assumption [3, 58] according to which the combination of metric values of fundamental subsystems of the coxal bone (sacro-iliac and ischio-pubic) should be used whenever possible in order to correctly determine sex. Our work has demonstrated that combinations of numerically limited variables, but which are still sufficient for skeletal sex determination, may also be extracted from partial **pelvises**. This can be of great use in the field of forensic anthropology.

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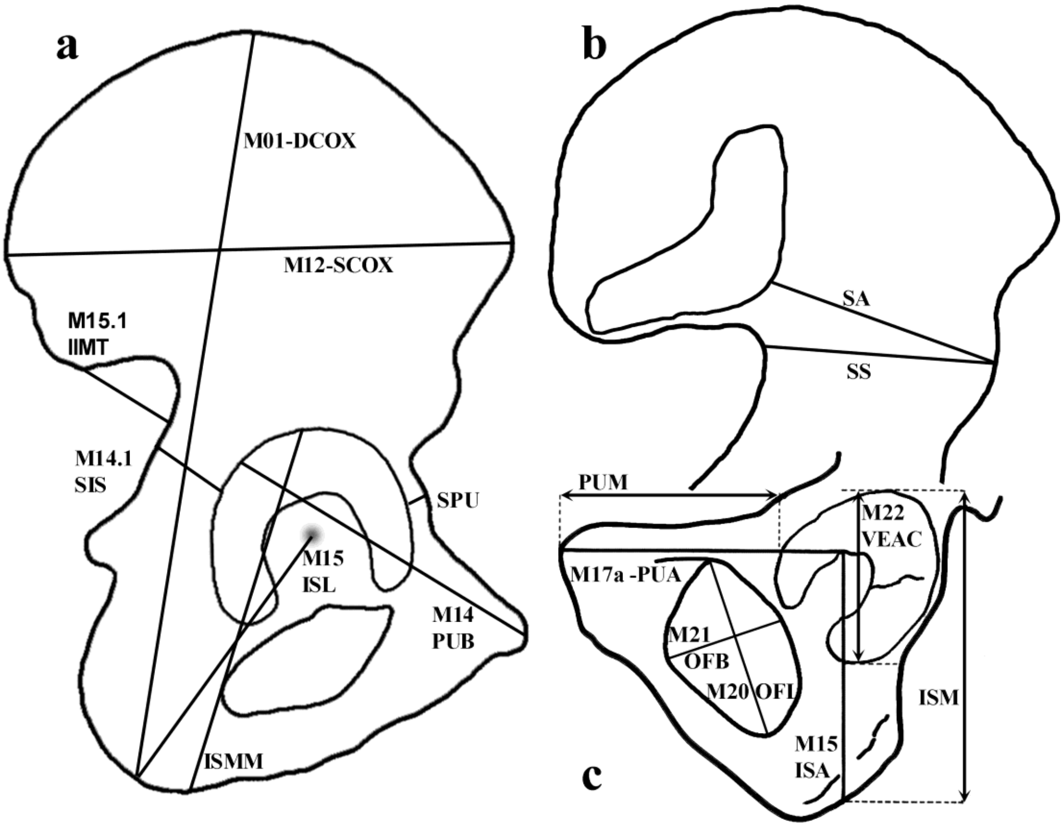

Fig. 1
The measurements for coxal bones. External surface (a); internal surface (b), sacro-iliac segment; external surface (c), ischio-pubic segment (see Table 1 for Codes).

Table 1

Osteometric measurements of the coxal bone.

M&S[a]	Code	Brief Definition	Source
M01	DCOX[b]	Coxal bone height, maximum; measured from the ischial tuberosity to the most superior point of the iliac crest.	[53]
M12	SCOX[b]	Iliac breadth, maximum; measured from the antero-superior to the postero-superior iliac spines.	[53]
M14	PUB	Acetabular - symphyseal breadth (acetabulum included); Measured from the superior-medial point of the pubic symphysis to the posterior margin of the acetabulum.	[53]
M14.1	SIS	Cotylo-sciatic breadth; Measured from the lateral border of the acetabulum to the midpoint of the anterior border of greater sciatic notch.	[53]
M15	ISL	Ischium length; Measured from the deepest point of the glenoid cavity to the ischial tuberosity.	[53]
M15.1	IIMT	Incisura ischiadica major height; Measured from the anterior border of the greater sciatic notch to the postero-inferior iliac spine (intersection between the auricular surface and the posterior border of greater sciatic notch).	[53]
M22	VEAC	Acetabulum height, maximum; vertical diameter measured on the acetabular rim on the prolongation of the main axis of the ischium.	[53]
	PUM	Pubis length, modified; Measured from the superior point of the pubic symphysis to the nearest acetabulum border.	[3, 12]
	ISM	Ischium length, modified; Measured from the ischial tuberosity to the far border of the acetabulum.	[3, 12]
M17.a	PUA	Pubis length, acetabular; Measured from the superior point of the pubic symphysis to the acetabular point.	[54-55]
M15.a	ISA	Ischium length, acetabular; Measured from the ischial tuberosity to the far border of the acetabular point.	[54-55]
	SPU	Cotylo-pubic breadth; Measured from the most lateral acetabular point to medial border of the pubis (perpendicular to the axis of the pubis).	[56]
	ISMM	Ischium length, post-acetabular; Measured from the most anterior-inferior point of the ischial tuberosity to the farthest point on the acetabular rim.	[15, 17]
	SS	Spino-sciatic length; Measured from the antero-inferior iliac spine to the deepest point of the greater sciatic notch.	[56]
	SA	Spino-auricular length; Measured from the antero-inferior iliac spine to auricular point (intersection between arcuate line and auricular surface)	[56]
M20	OFL	Obturator foramen length; Measured from the most superior point of the superior border to the farthest point on the inferior border.	[53]
M21	OFB	Obturator foramen breadth; maximum distance from the posterior to the anterior border (perpendicular to the foramen length).	[53]

For each measurements the following are reported: Martin's number (when possible); a work code (in general, those reported in the literature); a brief definition with landmarks needed to take the measurement; and bibliographical references in which the measurement is described in detail.

a, Martin and Saller, [52]; b, spreading caliper, otherwise sliding caliper.

Table 2

Intra-observer Technical Error of Measurements (TEM), between two repeated series of measurements; A paired t-test between the two series of measurements is also reported.

Variable	N	N%	N TOT	MEAN 1st	SD 1st	MEAN 2nd	SD 2 2nd	TEM[a]	RTEM %[b]	R[c]	Stat t	P(T<=t) 2t
M01-DCOX	39	28	141	196.808	10.065	196.897	10.072	0.516	0.262	0.987	-0.764	0.449
M12-SCOX	34	27	124	150.247	5.890	150.459	6.093	0.529	0.352	0.985	-1.695	0.099
M14-PUB	33	29	113	112.918	5.719	112.912	5.844	0.472	0.418	0.984	0.051	0.959
M14.1-SIS	46	28	165	37.226	3.148	37.126	3.242	0.364	0.978	0.989	0.095	0.190
M15-ISL	50	31	163	73.266	4.492	73.422	4.593	0.545	0.744	0.990	-1.446	0.155
M15.1-IIMT	46	30	154	45.676	5.422	45.604	5.273	0.675	1.480	0.989	0.505	0.616
M22-VEAC	51	31	164	48.765	3.807	48.645	3.857	0.461	0.946	0.990	1.320	0.193
PUM	32	29	111	68.316	4.902	68.250	4.746	0.390	0.572	0.984	0.667	0.510
ISM	51	32	159	97.278	6.091	97.318	6.101	0.482	0.549	0.990	-0.407	0.685
M17a-PUA	32	29	112	77.147	5.043	77.059	5.086	0.435	0.564	0.984	0.800	0.430
M15a-ISA	51	31	162	83.275	4.960	83.137	4.951	0.375	0.451	0.990	1.892	0.064
SPU	40	29	136	25.713	3.976	25.553	3.968	0.370	1.443	0.988	1.883	0.067
ISMM	49	31	157	100.531	6.826	100.633	6.713	0.569	0.566	0.990	-0.886	0.380
SS	43	29	147	69.167	5.300	69.030	5.258	0.639	0.924	0.988	0.996	0.325
SA	43	30	145	76.481	4.987	76.365	5.005	0.480	0.628	0.988	1.127	0.266
M20-OFL	37	30	125	49.916	4.032	49.730	3.997	0.623	1.251	0.986	1.299	0.202
M21-OFB	35	29	119	32.903	2.816	32.797	3.088	0.539	1.642	0.986	0.816	0.420

N: number of re-measured coxal bones; N%: number expressed in percentage; NTOT: total number of measurable coxal bones (considering the state of preservation); MEAN and SD: mean (expressed in mm), and standard deviation for the first and second series of measurements; TEM: Technical Error of Measurements; RTEM: relative TEM; R: reliability coefficient.

a, TEM = $\mathrm{SQR}(\sum D^2/2N)$, (D, deviations; N, number of cases remeasured); b, RTEM = TEM / VAV*100; VAV, Variable Average Value; c, $R = 1-((\mathrm{TEM})^2/(\mathrm{SD})^2)$; see [48-50].

Table 3

Paired t-test performed between right and left coxal bones to determine degree of asymmetries.

Variable	N	Mean.Diff.	SD	CI 95%	t(n)2t	p2t
M01-DCOX	64	- 0.275	1.238	0.309	-1.777	0.080
M12-SCOX	54	- 0.039	2.037	0.556	-0.140	0.889
M14-PUB	47	0.221	1.453	0.427	1.044	0.302
M14.1-SIS	74	-0.163	1.251	0.290	-1.124	0.264
M15-ISL	79	-0.121	0.832	0.186	-1.298	0.198
M15.1-IIMT	72	0.114	1.482	0.348	-0.652	0.516
M22-VEAC	80	0.262	1.293	0.288	1.816	0.073
PUM	47	0.036	1.367	0.401	0.181	0.857
ISM	77	-0.214	1.231	0.279	-1.527	0.131
M17a-PUA	47	0.402	1.410	0.414	1.955	0.057
M15a-ISA	78	-0.065	1.304	0.294	- 0.443	0.659
SPU	59	-0.142	1.422	0.370	-0.769	0.445
ISMM	75	0.267	1.267	0.291	1.823	0.072
SS	67	-0.258	1.683	0.410	- 1.256	0.213
SA	65	-0.041	2.188	0.542	- 0.153	0.879
M20-OFL	54	-0.065	1.242	0.339	- 0.383	0.703
M21-OFB	49	-0.039	1.087	0.312	- 0.250	0.804

N: number of coxal bone pairs; Mean.Diff: mean difference (measured in mm); SD: Standard Deviation; CI: Confidence interval; t(n)2t: t value and associated probability (two-tail).

Table 4

Normal distribution of male and female coxal bone dimensions assessed with the Kolmogorov-Smirnov one-sample test using a standard normal distribution (Lilliefors test). Two-sample homogeneity of variance test for male and female groups.

	Normal distribution test						Variance test				
	Males			Females							
Variable	N	MaxDiff	LP2t	N	MaxDiff	Lp2t	95% Conf.		F-ratio	df	p-value
M01-DCOX	63	0.109	0.060	78	0.069	0.428	0.523	1.358	0.838	62, 77	0.472
M12-SCOX	57	0.116	0.053	67	0.107	0.053	0.900	2.488	1.489	56, 66	0.121
M14-PUB	54	0.095	0.247	59	0.108	0.085	0.541	1.567	0.918	53, 58	0.753
M14.1-SIS	70	0.084	0.243	87	0.073	0.282	0.988	2.437	1.543	69, 86	0.056
M15-ISL	76	0.101	0.053	87	0.082	0.150	0.987	2.384	1.528	75, 86	0.057
M15.1-IIMT	71	0.058	0.791	83	0.074	0.298	0.718	1.783	1.127	70, 82	0.600
M22-VEAC	77	0.067	0.496	87	0.084	0.130	0.643	1.549	0.995	76, 86	0.987
PUM	53	0.082	0.464	58	0.075	0.549	0.334	0.977	0.569	52, 57	0.041
ISM	75	0.102	0.053	84	0.096	0.053	0.554	1.354	0.864	74, 83	0.523
M17a-PUA	53	0.104	0.156	59	0.066	0.736	0.693	2.019	1.178	52, 58	0.542
M15a-ISA	76	0.080	0.244	86	0.060	0.578	1.007	2.439	1.562	75, 85	0.047
SPU	62	0.087	0.274	74	0.076	0.330	0.690	1.820	1.115	61, 73	0.654
ISMM	75	0.101	0.054	82	0.097	0.055	0.706	1.733	1.104	74, 81	0.663
SS	68	0.106	0.057	78	0.049	0.967	0.816	2.076	1.297	67, 77	0.270
SA	68	0.095	0.129	76	0.061	0.658	0.418	1.07	0.669	67, 75	0.093
M20-OFL	57	0.116	0.054	68	0.093	0.143	0.501	1.381	0.827	56, 67	0.467
M21-OFB	54	0.085	0.393	65	0.082	0.310	0.661	1.869	1.104	53, 64	0.701

N: number of cases; MaxDiff: maximum difference between distributions; Lp2t: Lilliefors probability (2-tail).

Table 5

Descriptive statistics of the coxal measurements (mm).

	Male					Female				
variable	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
M01-DCOX	63	193.0	226.0	210.4	7.854	78	177.0	212.5	193.2	8.580
M12-SCOX	57	140.0	170.0	155.7	7.933	67	138.0	170.0	152.4	6.502
M14-PUB	54	108.4	126.0	116.0	5.021	59	102.0	121.8	113.0	5.241
M14.1-SIS	70	35.0	46.0	40.3	3.184	87	30.0	41.0	35.3	2.563
M15-ISL	76	71.5	87.5	79.3	3.913	87	63.8	78.7	71.1	3.165
M15.1-IIMT	71	30.8	49.0	39.9	4.565	83	40.0	58.0	47.5	4.300
M22-VEAC	77	47.2	59.3	53.2	2.910	87	41.0	54.0	46.8	2.917
PUM	53	60.0	73.7	67.9	3.532	58	61.0	80.0	70.6	4.682
ISM	75	96.0	113.7	105.0	4.069	84	83.0	102.0	93.2	4.377
M17a-PUA-	53	70.7	91.0	79.3	4.988	59	68.7	89.0	79.8	4.596
M15a-ISA-	76	79.2	96.0	88.7	3.943	86	72.0	86.7	79.9	3.155
SPU	62	22.7	34.5	28.9	2.741	74	19.0	30.8	23.9	2.596
ISMM	75	98.0	117.5	108.7	4.682	82	88.0	105.9	96.6	4.457
SS	68	60.6	85.0	74.8	4.835	78	56.5	76.0	67.3	4.246
SA	68	64.4	84.0	75.4	4.822	76	66.0	90.0	77.5	5.904
M20-OFL	57	47.3	58.8	52.9	2.925	68	41.7	56.0	48.5	3.216
M21-OFB	54	27.4	38.2	33.0	2.523	65	26.8	37.5	32.8	2.401

N: Number of individuals; Min/Max: Minimum and Maximum values; Mean: Mean; and SD: Standard Deviation.

Table 6

Comparison between the male and female mean values of measurements, two-sample t-test (two-sided).

Variable	Mean.Diff	95% CI		t	df	p-value
M01-DCOX	17.219	14.451	19.987	12.300	139	**0.000
M12-SCOX	3.268	0.702	5.834	2.521	122	*0.013
M14-PUB	3.058	1.141	4.975	3.161	111	**0.002
M14.1-SIS	4.967	4.061	5.837	10.831	155	**0.000
M15-ISL	8.141	7.046	9.237	14.676	161	**0.000
M15.1-IIMT	-7.508	-8.921	-6.095	-10.499	152	**0.000
M22-VEAC	6.462	5.562	7.363	14.175	162	**0.000
PUM	-2.598	-4.170	-1.026	-3.276	109	**0.001
ISM	11.853	10.523	13.180	17.617	157	**0.000
M17a-PUA	-0.510	-2.305	1.285	-0.563	110	ns0.574
M15a-ISA	8.789	7.687	9.892	15.743	160	**0.000
SPU	5.090	4.183	5.997	11.101	134	**0.000
ISMM	12.185	10.744	13.626	16.703	155	**0.000
SS	7.492	6.007	8.978	9.970	144	**0.000
SA	-2.067	3.856	-0.278	-2.285	142	*0.024
M20-OFL	4.477	3.380	5.575	8.077	123	**0.000
M21-OFB	0.230	-0.671	1.130	0.506	111	ns0.614

Mean.Diff: mean difference; CI: Confidence interval; t: t value and associated probability (two-tailed). ns, not significant; *alpha 0.05%; **alpha 0.01%.

Table 7

Multivariate discriminant analysis, canonical discriminant functions (F.1 to F.8) (non-standardized) for coxal bone dimensions.

	Variable	F.1	F.1b	F.2	F.3	F.4	F.5	F.6	F.7	F.8
01	M01-DCOX	0.062	0.078	-0.084	0.065	0.078				0.121
02	M12-SCOX	-0.070	-0.055	-0.038						-0.110
03	M14-PUB	-0.140	-0.145	-	-0.114	-0.137				
04	M14.1-SIS	0.189	0.200	0.167	0.141	0.199				
05	M15-ISL									
06	M15.1-IIMT	-0.142	-0.139	-0.102	-0.137	-0.137	0.126	0.090	0.116	
07	M22-VEAC	0.140	0.128	0.068		0.134				
08	PUM			-0.132			0.116			
09	ISM		0.054		0.087		-0.208		-0.172	
10	M17a-PUA									
11	M15a-ISA	0.132								
12	SPU	0.144	0.157	0.148	0.171	0.131	-0.188	-0.273		
13	ISMM			-0.014						
14	SS	0.131	0.144	0.165	0.139	0.131		-0.220	-0.108	0.237
15	SA	-0.098	-0.111	-0.114	-0.113	-0.114		0.163	0.091	-0.144
16	M20-OFL									
17	M21-OFB	0.162	0.172							
	Constant	-15.784	-15.426	-12.607	-13.644	-12.326	12.020	6.202	12.532	-13.218
	error% M/F[a]	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
	N. M/F	43 / 47	43 / 48	45 / 47		45 / 54	51 / 56	57 / 68	62 / 72	55 / 61
	csgm M[b]	3.580	3.535	3.093	3.277	3.296	-2.506	-2.331	-2.179	2.114
	csgm F[b]	-3.276	-3.167	-2.962	-2.731	-2.747	2.282	1.954	1.876	-1.906
	sectioning point	0.152	0.184	0.0655	0.273	0.2745	-0.112	0.1885	0.1515	0.104
	distance[c]	6.856	6.702	6.055	6.008	6.043	4.788	4.285	4.055	4.020
	Eigenvalues	11.994	11.449	9.365	9.132	9.242	5.828	4.630	4.151	4.101
	Wilks's Lambda	0.077	0.080	0.096	0.990	0.098	0.146	0.178	0.194	0.196
	Approx. F-ratio	85.046	82.226	75.857	102.734	103.978	148.617	138.885	133.865	113.816
	df	11, 78	11, 79	10 -81	8, 90	8, 90	4, 102	4, 120	4, 129	4, 111
	p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N. var	11	11	10	8	8	4	4	4	4

a, attribution error %, Jackknifed, leave-one-out method for cross validation is used;
b, csgm: canonical scores of group means; c, distance between male and female csgm.

Unstandardized coefficient, constants and sectioning points are to be used to construct discriminant equation: e.g. the equation F8 is: y = -13.218 + (0.121 x M01-DCOX) + (-0.110 x M12-SCOX) + (0.237 x SS)+ (-0.144 x SA). Substituting for M01-DCOX, M12-SCOX, SS and SA in the equation will give a y value to be compared with the sectioning point (0.104). The group mean is greater in males than in females, so when y is greater than the sectioning point it indicates a male coxal bone instead of a female coxal bone.

Table 8
Multivariate discriminant analysis, canonical discriminant functions (F.1 to F.8), standardized by within variances.

	Variable	F.1	F.1b	F.2	F.3	F.4	F.5	F.6	F.7	F.8
01	M01-DCOX	0.530	0.078	0.084	0.556	0.670				0.990
02	M12-SCOX	-0.535	-0.055	-0.038						-0.792
03	M14-PUB	-0.746	-0.145		-0.609	-0.730				
04	M14.1-SIS	0.511	0.200	0.167	0.389	0.547				
05	M15-ISL									
06	M15.1-IIMT	-0.608	-0.139	-0.102	-0.590	-0.592	0.530	0.390	0.495	
07	M22-VEAC	0.426	0.128	0.068		0.404				
08	PUM			-0.132			0.485			
09	ISM		0.054		0.376		-0.876		-0.716	
10	M17a-PUA									
11	M15a-ISA	0.462								
12	SPU	0.374	0.157	0.148	0.428	0.327	-0.481	-0.685		
13	ISMM			-0.014						
14	SS	0.554	0.144	0.165	0.575	0.543		-0.962	-0.473	1.017
15	SA	-0.555	-0.111	-0.114	-0.634	-0.637		0.891	0.492	-0.776
16	M20-OFL									
17	M21-OFB	0.402	0.172							