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PAPER

ANTHROPOLOGY

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Discriminant Function Analysis for Sex Assessment in Pelvic Girdle Bones: Sample from the Contemporary Mexican Population

ABSTRACT: Sex assessment of skeletal remains plays an important role in forensic anthropology. The pelvic bones are the most studied part of the postcranial skeleton for the assessment of sex. It is evident that a population-specific approach improves rates of accuracy within the group. The present study proposes a discriminant function method for the sex assessment of skeletal remains from a contemporary Mexican population. A total of 146 adult human pelvic bones (61 females and 85 males) from the skeletal series pertaining to the National Autonomous University of Mexico were evaluated. Twenty-four direct metrical parameters of coxal and sacral bones were measured and subsequently, sides and sex differences were evaluated, applying a stepwise discriminant function analysis. Coxal and sacra functions achieved accuracies of 99% and 87%, respectively. These analyses follow a population-specific approach; nevertheless, we consider that our results are applicable to any other Hispanic samples for purposes of forensic human identification.

KEYWORDS: forensic science, forensic osteology, discriminant function analysis, sex assessment, Mexican population, coxal, sacrum

Sex estimation using human skeletal remains has long been a major focus of anthropological research, but in forensic science, it is a critical process with legal implications (1,2).

Several methods have been developed which provide criteria for sex assessment, focusing on visual (3–10) and morphometric analyses (11–26) of the pelvis bones. A number of studies have been undertaken for the purpose of sex estimation using postcranial and craniofacial discriminant function analysis from Mexican samples (27–32). However, the pelvis has not been studied.

Success rates for sex estimation are greater among adult individuals, because sexual differences in the skeleton are better defined than in immature specimens. The male pelvis is longer, robust, and displays more rugged features with marked muscle insertions. Males show a narrower sciatic notch with an acute angle, the acetabulum large and the pubis short with a narrower subpubic angle. In contrast, the female pelvis shows a wider sciatic notch with an obtuse angle. It has a preauricular sulcus, a smaller acetabulum, a longer pubis, and a wide subpubic angle (33).

The pelvic girdle bones are structurally related to organ support and are functionally articulated to facilitate the erect position, as well as permitting the bipedal locomotion of the human body (34–36). A particular characteristic of the pelvis is the configuration of an obstetrical ring, which is the main source of variation between sexes (37).

The implication is that pelvic morphology has considerable potential for sex assessment, and for this purpose, in the present study, discriminant functions were developed.

Materials and Methods

The sample examined here derives from the Osteological Collection of the Anthropology Section, Department of Anatomy, School of Medicine, National Autonomous University of Mexico (UNAM). One hundred and forty-six human skeletons were examined (42% females and 58% males), ranging in age from 21 to >67 years old; all well-preserved and without any osteo-pathologies or *postmortem* modifications caused by peeling.

The series corresponds to contemporary skeletons from unclaimed bodies recovered in diverse public health facilities (38). Following an agreement between the School of Medicine (UNAM), the Health Ministry and the Mexico City Government, the authors received permission to study the skeletons from the chief of the Anatomy Department who is officially responsible for the collection and has authorization from the Health Ministry.

Using sliding and spreading calipers and an osteometric board; 24 direct metrical parameters relating to both coxal and sacrum bones were measured (Tables 1 and 2; Figs 1 and 2).

The univariate statistical analysis was carried out in three stages; the first one was based on Shapiro-Wilk's Goodness-Fit test, which allowed us to determine whether or not it was possible to affirm a normal distribution. In the second stage, paired-sample *t*-tests were

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TABLE 1—*Measurement indicators in the coxal bones.*

Measurement	Code	Definition
Total pelvic height	TPH	Maximum height of coxal bone measured from the most inferior point of the ischial tuberosity to the most superior point of the iliac crest, using an osteometric board (39)
Total iliac width	TIW	The greatest distance between the antero-superior and the postero-superior iliac spines, measured using spreading calipers (39)
Minimum pubic width	MPW	Minimum distance from the supra-acetabular point (lowest notch of the antero-inferior iliac spine) to the deepest point within the greater sciatic notch (3)
Spino sciatic length	SS	Minimum distance between the antero-inferior iliac spine and the deepest point within the greater sciatic notch, using the sliding calipers (20)
Acetabular diameter	AD	Maximum diameter of the acetabulum measured in a superior to inferior direction using sliding calipers. The measurement was taken as the diameter of the acetabulum along the axis of the body of the ischium (40)
Transverse acetabular diameter	TAD	Maximum acetabular diameter from the pubic eminence on the acetabular rim, using sliding calipers (41)
Pubis length	PL	Measured using a sliding caliper from the acetabular point (46) to upper end of pubic symphysis (42)
Ilium length	IL	Measured using a sliding caliper from acetabular point (46) to the most distant point on iliac crest (42)
Ischium length	ISCHL	Measured using a sliding caliper from the acetabular point (46) to the most inferior point of the ischial tuberosity in which the axis of the ischium crosses the ischial tuberosity (42)

TABLE 2—*Measurement indicators in the sacrum bones.*

Measurement	Code	Definition
Real height	RH	The length of the straight line drawn from the median point in the posterior margin of the sacral base to that of the apex, using sliding calipers (43)
Anterior length	AL	Distance from a point on the promontory positioned in the mid-sagittal plane to a point on the anterior border of the tip of the sacrum measured in the sagittal plane, using sliding calipers (44)
Anterior superior breadth	ASB	Maximum transverse breadth of the sacrum at the level of the anterior projection of the auricular surface, using sliding calipers (44)
Mid-ventral breadth	MB	Measured as the distance between the most inferior point of the left and right auricular surfaces, using sliding calipers (45)
Anterior-posterior diameter of the base	APDB	Maximum possible diameter of the first sacral vertebra measured by taking one point on the antero-superior border and the other point on the postero-superior border, using sliding calipers (21)
Maximum transverse diameter of the base	TDB	Direct distance between the two most laterally projecting points on the sacral base measured perpendicular to the mid-sagittal plane, using sliding calipers (44)

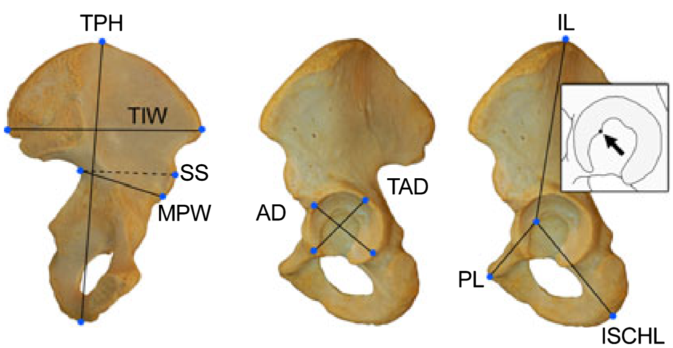

FIG. 1—*The nine measurements for coxal bones. Medial (left) and dorsolateral (center and right) view. Comment: the acetabular point is represented by the anterior angle of the superior lobe of the acetabular fossa (46).*

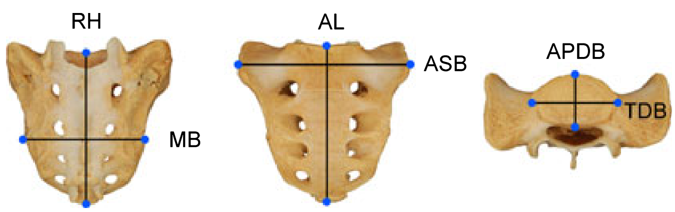

FIG. 2—*The six measurements for sacrum bones. Posterior (left), anterior (center), and superior (right) view.*

conducted to evaluate any significant differences ($\alpha = 0.05$) between sides. Finally, the independent-sample *t*-test was applied ($\alpha = 0.05$), comparing measurements between males and females.

The canonical discriminant analyses were performed to obtain functions for the right and left coxal and sacrum bones, and standardized coefficients were obtained using a stepwise method. Wilks' lambda was used to evaluate the proportion of the total variance in the discriminant scores not explained by differences among groups. The individual posterior probabilities of group membership were calculated in each case, with an equal prior probability for female and male groups. Statistical analysis was carried out using the SPSS (v. 15.0) software (IBM Corporation, Somers, NY).

Results

All variables showed a normal distribution in each side and sex, tested with the Shapiro-Wilks' test. The paired-sample *t*-tests showed differences ($p \leq 0.05$) in the right-side coxal bones, with respect to the left-side ones (data not shown). Tables 3 and 4 indicate that most of the dimensions for males are markedly higher, when compared with those of females. Means of all these dimensions were significantly different between sexes ($p \leq 0.05$) except for anterior superior breadth (ASB) of the sacrum. Only the pubic length (PL), the ASB of the sacrum, and the mid-ventral breadth of the sacrum (MB) measurements are greater in females.

The stepwise discriminant method produces the optimal combination of variables for minimizing the overlap of the group's

TABLE 3—*Means, standard deviation, and univariate independent-sample* t*-tests between sexes, for nine coxal variables.*

	Female					Male						
	n	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max	*t*	Significance
Right												
Total pelvic height	55	190.3	10.1	165	209	81	206.1	9.8	185	239	−9.129	0.000*
Total iliac width	55	146.8	9.5	125	166	81	151.4	8.5	129	179	−2.985	0.003*
Minimum pubic width	55	55.6	4.0	47	65	81	61.4	4.5	52	74	−7.698	0.000*
Spino sciatic length	55	66.1	4.8	57	78	81	71.8	5.3	58	85	−6.525	0.000*
Acetabular diameter	55	48.8	3.1	42	59	81	54.6	2.9	48	61	−11.138	0.000*
Transverse acetabular diameter	55	46.4	2.7	40	55	81	52.4	2.9	45	59	−12.214	0.000*
Pubis length	55	79.2	5.6	69	94	81	75.2	5.2	60	91	4.269	0.000*
Ilium length	55	121.7	6.9	107	137	81	130.2	6.6	115	148	−7.190	0.000*
Ischium length	55	81.0	5.1	69	92	81	89.2	5.7	71	105	−8.535	0.000*
Left												
Total pelvic height	55	190.4	10.2	165	213	81	206.9	9.7	187	242	−9.580	0.000
Total iliac width	55	147.3	8.9	125	166	81	151.6	8.7	128	180	−2.779	0.006*
Minimum pubic width	55	55.8	4.0	47	66	81	61.9	4.6	52	76	−8.108	0.000*
Spino sciatic length	55	66.3	4.0	56	76	81	72.5	5.6	59	88	−7.064	0.000*
Acetabular diameter	55	48.8	2.8	43	58	81	54.5	2.8	48	61	−11.592	0.000*
Transverse acetabular diameter	55	46.3	2.6	41	56	81	52.2	3.0	43	59	−11.906	0.000*
Pubis length	55	79.8	5.4	67	93	81	76.5	5.5	63	95	3.432	0.001*
Ilium length	55	122.2	6.8	106	137	81	130.2	6.6	115	145	−6.855	0.000*
Ischium length	55	80.7	4.5	69	90	81	88.9	5.1	79	106	−9.586	0.000*

Measurements are in millimeters. Independent-sample *t*-tests (two-tailed) of equality means between sex.
*Highly significant $p \le 0.01$.

TABLE 4—*Means, standard deviation, and univariate independent-sample* t*-tests between sexes for six sacrum variables.*

	Female					Male						
	n	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max	*t*	Significance
Real height	34	99.4	8.3	81	117	57	106.3	9.4	90	131	−3.571	0.001*
Anterior length	34	100.5	9.3	83	121	57	106.4	10.2	84	132	−2.752	0.007*
Anterior superior breadth	34	112.0	7.2	93	124	57	111.8	5.9	99	124	0.093	0.926
Mid-ventral breadth	34	84.7	7.3	67	100	57	81.4	5.4	69	93	2.468	0.016†
Anterior-posterior diameter of the base	34	28.4	2.9	21	35	57	31.1	1.9	27	35	−5.374	0.000*
Maximum transverse diameter of the base	34	45.4	3.9	39	54	57	50.7	3.0	43	57	−7.264	0.000*

Measurements are in millimeters. Independent-sample *t*-tests (two-tailed) of equal means between sexes.
*Highly significant $p \le 0.01$.
†Significant $p \le 0.05$.
The anterior superior breadth is nonsignificant ($p > 0.05$) and mid-ventral breadth is lowest significant.

centroids. In the stepwise method, the variables that contribute least to the prediction of group membership are eliminated. Wilks' lambda values show the significance of the variables included in the analysis for maximum discrimination, at each step ($p \le 0.05$).

The best measurements for discriminating sexes are transverse acetabular diameter (TAD), PL, total pelvic height (TPH), and total iliac width (TIW) in the right and left coxal bones. On the other hand, ASB, maximum transverse diameter of the base (TDB), and anterior-posterior diameter of the base (APDB) of the sacrum contribute more to the separation of the sexes.

Table 5 presents the discriminant functions for sexing, where coxal and sacra bones are employed. Based on Function 1, the posterior probabilities for the correct classification of cases in relation to the original group was 99.1% for the right coxal, 97.9% for the left coxal, and 86.8% for the sacrum.

The fragmentary and incomplete condition of materials derived from archeological and forensic contexts make morphometric analysis impossible, in some cases. In this paper, we present several functions using subsets for possible fragmentary bones (Table 5).

Figure 3 shows the range of variation for the first canonical discriminant function, for each one of the three pelvic girdle bones.

Discussion and Conclusion

Several authors have demonstrated the value of coxal bone metric data for the purpose of identifying sex, using human skeletal remains. Seidler (16) examined the Weisbach and Weninger collections, applying the discriminant function method with two, eight and 16 measurements for every right hip bone. He tested these functions on the Tyrol documented series and his results were highly discriminant to sex. Luo (18) studied the North-American population from the Human Identification Laboratory of the University of Arizona and found that 100% of the 230 individuals evaluated were accurately sexed, using discriminant analysis with direct and indirect pubis measurements. Dixit et al. (24) analyzed samples belonging to a Delhi Indian osteological collection. Twelve measurements and five ratios were recorded for the coxal bone and discriminant analysis was applied. Their results indicated that acetabular height, pelvic brim depth, minimum width of the ischiopubic ramus, and five pelvic ratios are all good sex indicators. Murail

TABLE 5—*Discriminant functions for right and left coxal and sacrum bones among contemporary Mexican population.*

	Discriminant Function	Wilks' Lambda	*F*	Significance	Sectioning Point	Probability of Sex Diagnosis (%)
Right coxal						
Function 1 (step 4)	*y* = 1.3973TPH – 0.7529TIW + 0.6481TAD – 1.0905PL	0.201	130.2	0.000	112.5129	99.1
Function 2 (step 3)	*y* = 1.3973TPH + 0.6481TAD – 1.0905PL	0.235	143.4	0.000	224.7574	92.7
Function 3 (step 2)	*y* = 0.6481TAD − 1.0905PL	0.318	142.4	0.000	−52.1837	79.2
Function 4 (step 1)	*y* = 0.6481TAD	0.473	149.2	0.000	32.0294	85.3
Left coxal						
Function 1 (step 4)	*y* = 0.9724TPH − 0.6239TIW + 0.4288TAD − 1.1295PL	0.227	111.6	0.000	32.7827	97.90
Function 2 (step 3)	*y* = 0.9724TPH + 0.4288TAD − 1.1295PL	0.253	130.0	0.000	126.0363	94.50
Function 3 (step 2)	*y* = 0.4288TAD − 1.1295PL	0.354	121.1	0.000	−67.1168	72.80
Function 4 (step 1)	*y* = 0.4288TAD	0.486	141.7	0.000	21.1362	86.80
Sacrum						
Function 1 (step 3)	*y* = −0.8549ASB + 0.6765APDB + 0.8824TDB	0.465	33.4	0.000	−33.1028	86.80
Function 2 (step 2)	*y* = −0.8549ASB + 0.8824TDB	0.552	35.7	0.000	−53.2410	75.10

Discriminant function (stepwise), Wilks' lambda, *F*-ratio, significance, sectioning point, and percentage of cross-validated grouped cases correctly classified for each bone are shown. When the calculated *y*-value is less than the sectioning point the individual is female, otherwise it is male. Function 1 assessed the higher probabilities of sexing. Only the best combinations of variables, which correctly classify more than 70% of individuals, are included. Subsets of functions 2–4 are an alternative for possible fragmentary bones.

APDB, anterior-posterior diameter of the base; ASB, anterior superior breadth; PL, pubic length; TAD, transverse acetabular diameter; TDB, transverse diameter of the base; TIW, total iliac width; TPH, total pelvic height.

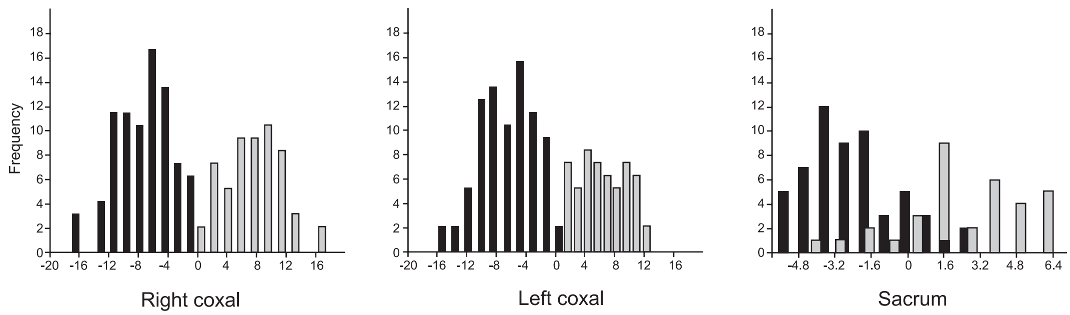

FIG. 3—*First canonical discriminant function for each pelvic girdle bone. Females in black and males in gray. It should be noted in coxal bones that only a few cases overlap each other; however, contrastingly, there is greater overlap concerning the sacrum.*

et al. (22) proposed that worldwide variations for hip bone measurements could be analyzed, thus indicating whether particular specimens were likely to be male or female. Their results were 90% accurate. Flander (15) analyzed six measurements from African American and Caucasian sacra by applying discriminant function and demonstrated that the transverse diameter is a highly reliable indicator for determining sex, with *c.* 90% accuracy. Kimura (17) studied the transverse diameter of the sacral base, the width of the sacral wing, and the base-wing index from Japanese, Caucasian, and African American series. The measurements were subjected to discriminant function analysis with a resulting prediction success of 75.32% among Japanese, 80.88% among American Caucasians, and 82.70% among African Americans. Kimura (17) suggested that concerning the sex differences of the sacrum; shape was more important than size.

Moore-Jansen and Plochocki (19) recorded a total of 27 measurements from a sample comprising 228 sacra from African American and Caucasian specimens, pertaining to the Robert James Terry collection. Measurements included breadths, lengths, chords, and subtenses and subsequently a stepwise discriminant procedure was carried out to identify optimal models for estimating sex. A strong group-specific pattern of sexual dimorphism in the sacrum was evident, with highly accurate sex estimation being derived from female sacra (96% among black females; 88% among white females), compared with relatively poor sex estimation among males (ranging between 53% and 58%).

Benazzi et al. (25) conducted discriminant function analysis for sex prediction on 114 Bolognese and Sassarese Italians adult sacra. The maximum transverse diameter, maximum superior breadth, as well as the area and perimeter of the body of the first sacral vertebra, were measured. This resulted in a high percentage of correct sex classification which exceeded 80% accuracy.

It is evident from our results that human pelvic girdle bones present sufficient information to indicate sexual differences. The patterns of variation in size depending on sex are heterogeneous in hip bones. Generally, whereas the overall size of the male pelvis is larger than that of females, the size of the bony birth canal is larger in females. Tague (47) found that differences in the size and shape of the specialized anatomical segments of the pelvis are related to childbirth.

Our results indicated that data from the pelvic girdle bones were suitable for sex estimation by discriminant function. The morphometric method offers an alternative to the extensive training required for the visual approach and reduces inter-observer errors (10). The discriminant function analysis offers several advantages because it is inherently more objective, with greater replicability (18).

As is evident in Fig. 3, few cases were misclassified and the highest probabilities for sexual diagnosis were obtained from discriminant analysis, with the coxal bone measurements achieving an accuracy rate of 99%. The use of the sacrum bone should also be discussed as it has proven unreliable for sex determination, due to a low percentage of correct classifications compared with the coxal bone. For the implementation of this method, we recommend simultaneously comparing all discriminant functions for the same specimen bones, in order that the results should be consistent and conforming.

In general terms, the use of population-specific discriminant function is motivated by the fact that populations differ in terms of body size and degree of sexual dimorphism (22,26).

The present study is the first successful discriminant function analysis carried out using pelvic girdle bones from a skeletal reference collection, pertaining to the contemporary Mexican-mestizo population; we are confident that our discriminant function will be applicable to other Hispanic contemporary samples for both forensic science and forensic osteology.

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