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SHAPE ANALYSIS OF *INCISURA ISCHIADICA MAJOR*: DEFINITION OF REFERENCE OUTLINES IN SEXING THE HUMAN PELVIS

ABSTRACT: Series of reference outlines expressing variations of morphological features, mainly related to sexual dimorphism, are commonly used in anthropological practice. Usually, these are defined on the basis of observer experience and the degree of expression of the examined character is explained by a score. The level of objectivity in scoring morphological features can obviously vary depending on the observer's skilled eye and can be bound with difficulty to standardization criteria. Considering these exigencies, we explored the possibility of setting series of reference outlines of the incisura ischiadica major*, associating each form in the series to a suitable probability value expressing its sexual dimorphism. This value is obtained by comparing the analytic numerical descriptors obtained by the outlines in the series to those obtained by studying the shape differences, by Fourier analysis, in a sample of* incisurae *taken from pelvises of known sex. Reference outlines validated in this way through analytic morphometry improve the quality of observation, reducing the level of subjectivity of traditional visual scoring.*

KEY WORDS: Greater sciatic notch sexing – Analytic scoring – Reference outlines – Fourier analysis

INTRODUCTION

The quantitative description of form consists of procedures which facilitate the mapping of visual information into a mathematical representation. Methods of quantifying morphology, widely used in anthropology, are based on relatively simple procedures for dimensional evaluation, which are, however, limited for the analysis of shape. Since the shape of an anatomical region needs to be reduced to quantifiable characteristics, one possible approach is to consider outlines or profiles describing these regions as curves, leading to a description based on analytic geometry.

Among the procedures used for shape analysis of boundaries, interpolation by Fourier polynomials is a suitable method of providing a precise representation of any irregular biological form with very low residuals.

The boundaries to be described, dimensionally normalized and standardized for position, are decomposed by the analysis into series of sine/cosine coefficients (from which amplitude and phase angle are obtained) for a finite number of sinusoidal harmonics; these data are then used to describe and compare the studied morphologies.

The results concerning the analytic definition through Fourier analysis of two series of reference outlines of the greater sciatic notch, to be used in sexing the human pelvis, are here reported.

Series of reference outlines expressing variations of morphological features, mainly related to sexual dimorphism, are commonly used in anthropological practice: for the sciatic notch, the classic Açsàdi and Nemeskéri scheme (1970), or the "Ideal shape analysis of form" proposed by Novotný (1981) in which "length", "symmetry" of the arms and "recursiveness" of the superior segment of the notch are considered.

Usually, these series are defined on the basis of observer experience and the degree of expression of the examined character is explained by a score. The level of objectivity in

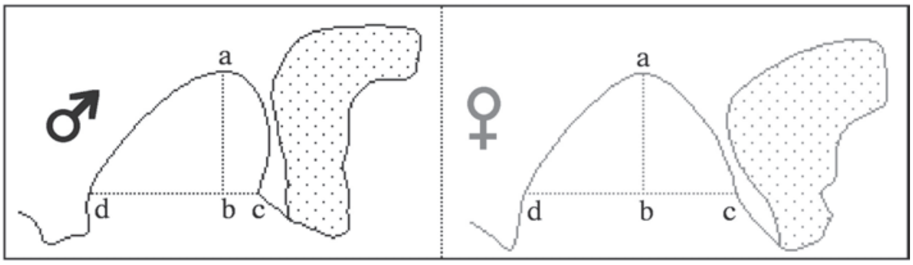


FIGURE 1. Greater sciatic notch, standard positioning and reference points used to define the boundaries for shape analysis; the profiles were dimensionally normalized by scaling each boundary to the same value of depth (a–b) so as to reduce size influences.

scoring the degree of expression of morphological features can obviously vary depending on the observer's skilled eye and can be bound with difficulty to standardization criteria.

Considering these exigencies, we explored the possibility of setting series of reference outlines of the *incisura ischiadica major* associating each form in the series to a suitable probability value expressing its sexual dimorphism. This value is obtained by comparing the analytic numerical descriptors obtained by the series to those obtained by studying the shape differences, by Fourier analysis, in a sample of *incisurae* taken from pelvises of known sex.

Reference outlines validated in this way through analytic morphometry can improve the quality of the observation, reducing the level of subjectivity of traditional visual scoring.

MATERIALS

The boundaries of the *incisura ischiadica major* on 97 male and 98 female *os coxae* were considered; the material, from the 19th and 20th centuries, came from Czech and German collections, of known sex, from the Institutes of Anatomy in Prague and Brno and was traced as silhouettes by V. Novotný (Novotný 1986). Various kinds of analytic descriptions of the sample are reported in several papers (Vacca *et al.* 1997, Novotný *et al.* 1993, 1997, Di Bacco *et al.* 1995).

METHODS

Standard positioning and dimensional normalization of the boundaries

For each *os coxae* the boundary of the *incisura ischiadica* was considered in the trait between the base of the *spina ischiadica* and *the spina iliaca posterior inferior* till the point where the latero-superior segment of the *incisura* meets the extremity of the *facies auricularis* (*Figure 1*: points c, d).

The above reference points were placed in a system of orthogonal Cartesian axis on the same ordinate value; the profiles were dimensionally normalized with an optical scaling attributing the same value of depth to each one (segments a–b) so as to reduce size influences.

Data acquisition

In each profile the latero-superior and the latero-inferior parts (*Figure 1*: a–c and a–d traits) were examined independently; thus, for each *incisura* two separate series of 90 equispaced abscissa values were serially acquired starting from the deepest point of the *incisura* (*Figure 1*: point a) up to the two extremities of the notch (*Figure 1*: points c and d).

Acquisition and analytical data processing were performed using S.A.M. (Shape Analytic Morphometry) system. The system is constituted by an integrated architecture of analytical procedures which allow a complete description of the shape in two-dimensional forms. For this work, mainly the section dedicated to the description of open curves using the trigonometric interpolation according to Fourier polynomial was used (Pesce Delfino *et al.* 1997).

Analytical description of the boundaries: Fourier analysis

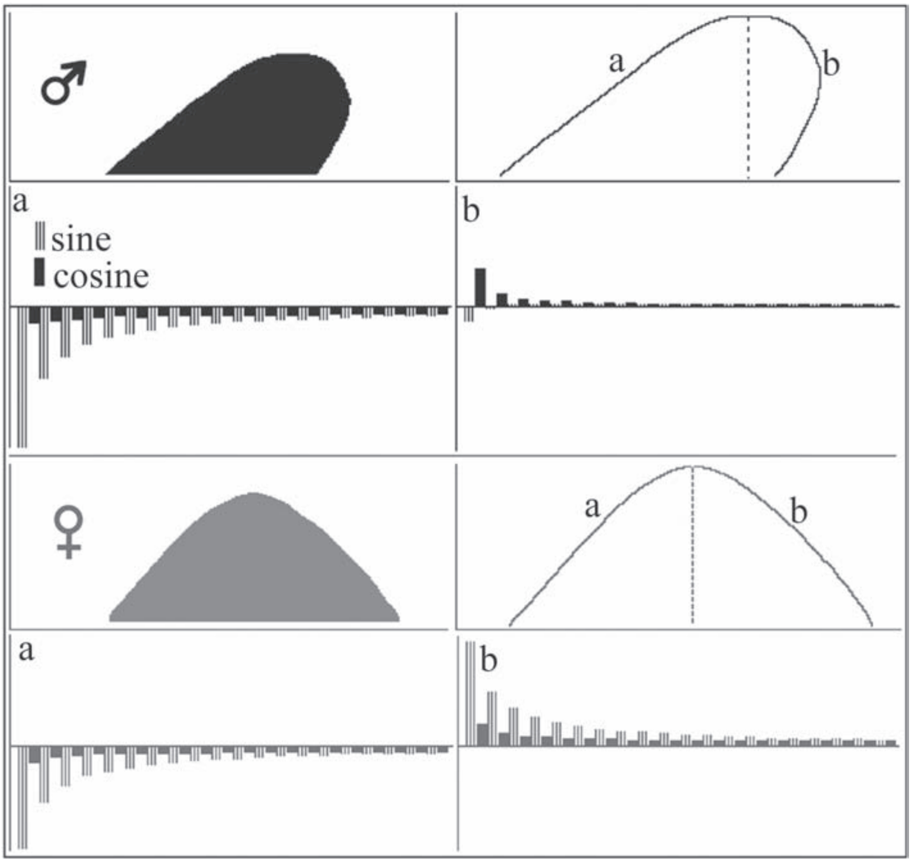
Each data series consisting in distances between the 90 points of the profiles and the corresponding points on the reference straight line subdividing the notch (*Figure 1*: points a–b) was submitted to the trigonometric polynomial; the result is Fourier sine/cosine coefficients for a number of harmonic contributors not exceeding half of the number of points which constitute the series. By the coefficients the amplitude and phase values of the single contributing harmonics are then calculated, amplitude being related to absolute size of coefficients and phase coming from sign and size ratio of sine/cosine coefficients.

The harmonic coefficients (*Figure 2*) are calculated in increasing order corresponding to the period of the sinusoidal contributors, so they are orthogonal (statistically independent).

The procedure gives a description, with very low residuals, of any irregular periodic one-dimensional oriented data series. It is possible to make a partial or overall resynthesis, simply by algebraic adding of the contributing harmonics; further, when different profiles are described, it is possible to make comparisons through graphic superimposition of single sinusoidal contributors or of partial additions of subsets of these contributors establishing in this way their contribution in determining the studied shape.

A large variety of applications of Fourier analysis both in phylogenetic and ontogenetic studies are reported in

FIGURE 2. Sample of a male and a female treated boundary before (filled outlines) and after dimensional normalization and Fourier spectra (first 15th harmonics), obtained for: a) latero-inferior ramus, b) latero-superior ramus.



Lestrel (1997), together with an exhaustive explanation of the technique.

The extracted Fourier variables (amplitudes and phase angles) were utilized in performing multivariate discriminant analysis, to set linear functions efficacious in distinguishing the male and female groups.

The following results still contain a certain amount of dimensional information and currently, work is underway to separate further information regarding dimension from that of shape.

RESULTS

Three discriminant equations were defined for the latero-inferior ramus, the latero-superior ramus and for the complete notch respectively (*Table 1*). The best results were obtained using amplitude and phase angles from both the latero-superior ramus and the latero-inferior ramus; by utilizing a linear combination of 14 variates the correct attribution was obtained in 191 data cases out of 197 (97% of cases were correctly attributed) (Vacca *et al.* 1997).

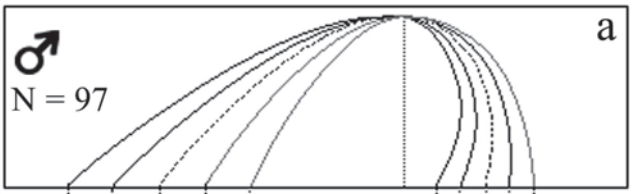
The equations giving the results reported in *Table 1* were used to classify the outline reference series defined as follows:

1) Definition of reference outlines exploring the central area of the sample variability.

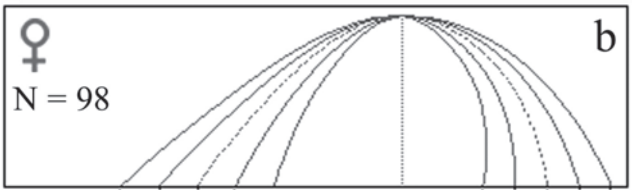
The first reference series is constituted by the mean profile (dotted lines in *Figure 3*) and by the mean profile ± 1 and ± 2 standard deviation, so that 5 profiles for the male (*Figure 3a*) and 5 profiles for the female group (*Figure 3b*) were obtained; each of them was described by Fourier analysis and then reclassified on the basis of previously obtained discriminant equations.

TABLE 1. Results of the discriminant analysis performed by using Fourier data on the latero-inferior ramus and on the latero-superior ramus separately and on both rami together (Vacca *et al.* 1997).

Rami	Data cases		Classified	Misclassified	Classified %
function No. 1 latero-inferior	males	97	75	22	77.319
	females	98	79	19	80.612
	total	195	154	41	78.965
function No. 2 latero-superior	males	97	93	4	95.876
	females	98	92	6	93.877
	total	195	185	10	94.876
function No. 3 latero-inferior & latero-superior	males	97	94	3	96.907
	females	98	95	3	96.939
	total	195	189	6	96.923



I	I \ S	-2SD (0.998)	-1SD (0.998)	$\bar{X}$ (0.941)	+1SD (0.810)	+2SD (0.193)
0.993	-2SD	1.000	1.000	1.000	0.996	0.980
0.928	-1SD	0.999	0.999	0.998	0.978	0.904
0.977	$\bar{X}$	0.994	0.996	0.990	0.881	0.616
0.340	+1SD	0.965	0.978	0.948	0.566	0.220
0.058	+2SD	0.849	0.899	0.787	0.210	0.054



I	I \ S	-2SD (0.819)	-1SD (0.902)	$\bar{X}$ (0.977)	+1SD (0.998)	+2SD (1.000)
0.183	-2SD	0.383	0.187	0.954	0.993	1.000
0.528	-1SD	0.685	0.447	0.986	0.998	1.000
0.816	$\bar{X}$	0.880	0.731	0.996	0.999	1.000
0.916	+1SD	0.966	0.913	0.999	1.000	1.000
0.955	+2SD	0.989	0.972	1.000	1.000	1.000

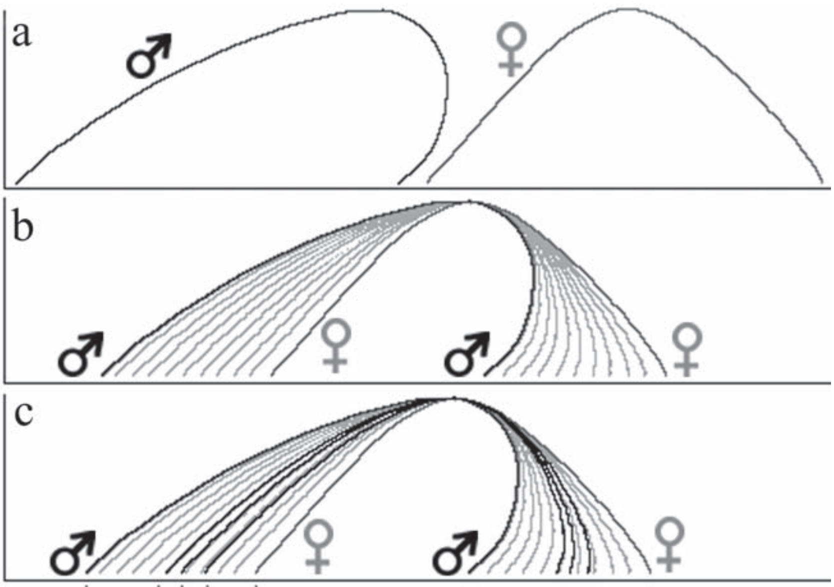
FIGURE 3. Reference outlines defined on the basis of the mean (N=97) male (a) and the mean (N=98) female (b) profiles plus and minus 1 and 2 standard deviation values. The calculated probability of group appurtenance, obtained by the discriminant equations based on Fourier data, is reported for each single profile (S, superior ramus; I, inferior ramus) and for their possible combinations.

The probability of group membership in respect to the given group is reported (*Figure 3*) for the superior and inferior ramus separately and for the possible combination of forms.

2) Definition of reference outlines exploring the limits of the sample variability.

Two notch boundaries for which the highest scores were obtained in discriminant analysis for the male and female groups respectively (corresponding traditionally speaking to a hyper-male and hyper-female morphology) are first selected (*Figure 4a*). Superimposing the two notch profiles, the range of variability for the male and female groups for the superior and inferior arm respectively, is defined (*Figure 4b*). The empty space between the male and female curves is then filled by interpolation according to Lagrange (Pesce Delfino *et al.* 1986); through this kind of interpolation, intermediate shapes are obtained by progressively varying the weight of two original profiles (grey outlines in *Figure 4b*).

The interpolated curves were described by Fourier analysis and 3 curves for the superior arm and 3 for the inferior arm (*Figure 4c*, black outlines) were identified, for



d

	1.000	0.746	0.491	0.212	0.000
1.000	1.000	0.990	0.983	0.974	0.000
0.765	0.989	0.880	0.816	0.573	0.000
0.505	0.984	0.833	0.750	0.476	0.000
0.251	0.996	0.693	0.576	0.292	0.000
0.000	0.875	0.357	0.251	0.092	0.000

FIGURE 4. Reference outlines defined by filling the space variability between a hyper-male and a hyper-female morphology (a) by intermediate forms synthesized through Lagrange interpolation (grey outlines in b). 3 intermediate curves for the superior arm and 3 for the inferior arm (c, black outlines) were identified for which discriminant analysis gives a probability of group appurtenance of about 0.75, 0.50 and 0.25 respectively (if tested in respect to the male group, that is 0.25, 0.50 and 0.75 if tested in respect to the female group). The probability of group appurtenance is reported for each single profile and for their possible combinations.

which the discriminant analyses give a probability of group appurtenance of about 0.75, 0.50 and 0.25 respectively (if tested in respect to the male group, that is 0.25, 0.50 and 0.75 if tested in respect to the female group).

The probability of group appurtenance obtained by the multivariate discriminant analysis for the original profiles, the selected intermediate Lagrange profiles and their possible combinations are reported in *Figure 4*.

CONCLUDING REMARKS

The increase of discriminant power obtained by analytic description in respect to the dimensional one recalls the problem of using proper variables for studying form.

The relatively low efficacy of the morphoscopic and scoring analysis is, probably, related to the general fact that while our visual perception is very effective in shape recognition, we are not so able to describe shape. Thus, tools able to help us in this second aspect of analysis are needed.

The perceptive logic we follow in recognizing form, in fact, is not easy to define, but it is probably not necessary to fully understand it in order to reach the goal, if there are tools (mathematic tools in this case) able to describe what we are able to see and that can be univocally referred to the morphological features.

On the basis of the results obtained and considering the defined reference outlines, some basic or invariant morphological features that can help the sex diagnosis of the sciatic notch can be outlined: for example, beside the already known features like length, divergence of the rami and the recursive trend of the superior ramus (Novotný 1986), another feature that seems to play a certain role in determining correct sex attribution is related to the placement of maximum convexity on the superior ramus.

The maximum convexity position placed rather high in the profile drives the description in a masculine sense; if the maximum convexity point is placed at the end of the profile the ramus is analytically defined in a feminine sense.

In addition, the recursive trend of the latero-superior ramus in true male morphology must be accompanied by the allocation of the maximum convexity point in the upper part of the ramus, otherwise misclassification can occur.

The defined reference outlines for the sciatic notch validated through analytic procedures can be used in anthropological practice reducing the level of subjectivity of the traditional scoring attribution.

REFERENCES

ACSÀDI G. Y., NEMESKÉRI J., 1970: *History of Human Life-span and Mortality*. Akademiai Kiadò, Budapest. 346 pp.

DI BACCO M., MOCCELLIN V., PACCIANI E., VACCA E., 1995: Diagnosis of sex from the profile of the incisura isciadica major. *Riv. Antrop*. 73: 217–224.

LESTREL P. E., 1997: *Fourier Descriptors and their Application in Biology*. Cambridge University Press, Cambridge. 480 pp.

NOVOTNÝ V., 1981: *Pohlavní rozdíly a identifikace pohlaví pánevní kosti (Sex differences and identification of sex in pelvic bone)*. Ph.D. thesis. J. E. Purkyně University, Brno.

NOVOTNÝ V., 1986: Sex determination of the pelvic bone: A system approach. *Anthropologie* XXIV, 2–3: 197–206.

NOVOTNÝ V., PESCE DELFINO V., POTENTE F., VANČATA V., VACCA E., 1997: Symmetry analysis of *incisura ischiadica major* in sexing the human pelvis. *Anthropologie* XXXIV, 3: 253–263.

NOVOTNÝ V., VACCA E., VANČATA V., PESCE DELFINO V., 1993: Differenze sessuali rilevabili sulla *incisura ischiadica major* del bacino dell'uomo: confronto tra analisi metrica e analisi della forma. *Antrop. Cont.* 16, 1–4: 229–237.

PESCE DELFINO V., LETTINI T., VACCA E., 1997: Heuristic adequacy of Fourier descriptors: Methodological aspects and application in morphology. In: P. E. Lestrel (Ed.): *Fourier Descriptors and their Application in Biology*. Pp. 250–293. Cambridge University Press, Cambridge.

PESCE DELFINO V., POTENTE F., VACCA E., LETTINI T., LENOCI R., MITOLO V., 1986: Ricerca di relazioni trasformative del profilo sagittale fronto-facciale degli ominidi. Proposta di alcune procedure. *Antrop. Cont.* 9, 1: 15–29.

VACCA E., NOVOTNÝ V., VANČATA V., PESCE DELFINO V., 1997: Shape analysis of *incisura ischiadica major* in sexing the human pelvis. *Anthropologie* XXXV, 3: 291–301.

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