SHAPE ANALYSIS OF INCISURA ISCHIADICA MAJOR IN SEXING THE HUMAN PELVIS

ABSTRACT: The problem of correctly sexing unknown skeletal material is given by the contradiction between the discrete classification according to genetically determined sex and the continuous transitions of somatic sexual characters of the phenotype. This is true for pelvic bones also, despite the fact that they are the most sexually differentiated bones of the skeleton.

The combination of metric characteristics of the two fundamental subsystems of os coxae (ischiopubic and sacroiliac) is not only necessary but is also sufficient for a multivariate discriminant analysis which separates completely the two sexes in a recent population.

The discriminant functions obtained by using the metric characteristics of the individual pelvic segments are less successful, namely in the sacroiliac segment.

To improve this result, keeping in mind the problem of sexing in unknown and partial pelvises, we have analyzed a sample of incisurae by using, instead of metric data, shape parametrical descriptions of the boundaries through Fourier analysis.

In this work 97 male and 98 female os coxae were considered, the material, of known sex, was of Czech and German origin, dated to the last century (about 1880-1980) from the collections of Institutes of Anatomy in Prague and Brno.

Data acquisition and treatment were performed by means of S.A.M. (Shape Analytical Morphometry) software-system; the system is constituted by an integrated architecture of analytical procedures which allow a complete description of the shape in two-dimensional objects.

The boundaries to be described, dimensionally normalized and standardized for the position, are decomposed by the analysis in 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 in performing multivariate discriminant analysis to set linear functions efficacious in distinguishing the male and female groups.

Having used various combinations of variables, the degree of correct attribution reached 97% of all cases.

The morphological features, more informative in determining the correct sex attribution, are then identified and discussed on the basis of the obtained results.

KEY WORDS: Sex determination – Pelvic bone – Fourier analysis – Incisura ischiadica major

INTRODUCTION

The problem of accurate sex determination on skeletal remains is complicated by the contradiction between the discrete classification according to genetically determined sex and the quasi-continuous variation of somatic sexual characters of the phenotype. While a simple analysis of sex differences, often, shows a certain overlapping of the two sexes, both in their size and shape, a normal human is either a man or a woman. Thus, the problem confronting
the osteologist/paleoanthropologist is often how to
determine the true sex of specimens with mixed male and
female features. This is true for pelvic bones also, despite
the fact that they are the most sexually differentiated bones
of the skeleton.

Thanks to its expansive development (i.e.
 multidirectional, multidimensional and multifactorial
growth and uneven timing of development) the bony pelvis
appears as a complicated, hierarchically integrated system
and simultaneously as an intersection point of various
factors determining the skeletal sexual dimorphism
(locomotion, reproduction, cultural evolution).

The single pelvic bone (or coxal) can be divided into
two evolutionary, functional and causally relatively
independent sub-systems, namely the ischiopubic and
sacroiliac segment.

The ischiopubic segment reflects well the phylogenetic
adaptation of the female small pelvis to the mechanical
conditions of parturition with a relatively large foetus.
The ontogenetic development of this segment is controlled by
hormones. The sexual difference is caused by the
remodelling of the female small, i.e. obstetric pelvis into
an adequately spacious birth canal first of all by pubis
elongation during puberty. The most representative
character of the small pelvis is the ratio of the longitudinal
dimensions of the pubis and the ischium.

The sacroiliac segment reflects the sexually
differentiated process of hominization: adaptation to the
verticalization of the body and bipedal locomotion. Dorsal
extension and downward shift of the ilium is advanced
further in males than in females where necessarily
dimensions of the pelvic cavity have to be preserved.
Because of the greater weight in males, the greater sciatic
notch is more expressed with the downward tendency
of the ilium. In females, the sciatic notch remains at a lower
developmental stage, sometimes forming only a flat arch.

This greater sciatic notch (incisura ischiadica major)
as a whole is the most representative character of the
sacroiliac segment. The sexually dimorphic shape of the
notch is inborn and seems to be under direct genetic control,
but the degree of its expression is influenced by local
factors.

The combination of the representative characters of the
two basic sub-systems is not only necessary but is also
sufficient for a multivariate discriminant analysis which
separates completely the two sexes in a recent population.

The discriminant functions obtained by using the
individual pelvic segments are less successful, namely in
the sacroiliac segment. Form these presented examples of
discriminant functions based on the dimensions of acatic
notch only, the zone of overlapping of the discriminant
scores of both sexes regarding the 25% of the studied data
cases is apparent (Novotný 1980, 1984).

In some females the pubic bone is markedly elongated
while the sciatic notch shows excessive narrowing. The
reduction of the sacroiliac segment is compensated for by
extension of the ischiopubic segment. According to the
principle of equifinality any of the main pelvic sub-systems
appears to be capable of compensating for the possible
deficiency of the opposite sub-system in order to preserve
the basic function of the system of a higher order, i.e.
spaciousness of the birth canal in the present case
(Novotný, Vancát 1983).

In these cases metric analysis fails completely.
Because of this kind of problem in determining sex
Novotný (1980) focused attention on studying only the
shape of the incisura. In order to derive the shape types
characteristic of one sex only, regardless of absolute size
and concrete variability, a special type of logical analysis
of an idealized shape was used. The idealized shape was
derived and scored from those characteristics of the
incisura profile that did not contradict each other: in males
the incisura ischiadica major in contrast with the opposite
sex is always narrower, deeper, more closed and the shorter
superior arm has recurvate course; in females the incisura
on the contrary is wider, shallower, more open and its
equally long arms diverge symmetrically forming a
parabolic arch. The key sex difference for the sciatic notch
is its superior arm behaviour. The shape variability based
on the scoring of form according the "ideal shape analysis"
principles is great, given that only 70 % of correct sex
attribution is obtained (Novotný 1980).

To improve this result, keeping in mind the problem of
sexing in unknown and partial pelvises, we started to study
the same samples of incisurae, on which the dimensional
analysis and the "ideal shape analysis" had been carried
out, using shape parametrical descriptions based on the
logic of the S.A.M. (Shape Analytical Morphometry)
software system (Ponce Delgino, Rocco 1983).

For a pilot study a reduced sample of pelvic bones were
selected covering the full range of variability of the incisura
according to Novotný’s "ideal shape analysis".
Encouraging preliminary results (Novotný et al. 1993)
suggested an extension of the analysis to a larger sample.

MATERIALS AND METHODS

In this work 97 male and 98 female os coxae were studied.
The material, of known sex, was of Czech and German
origin, dated to the last century (about 1880-1980) from
the collections of Anatomical Institutes in Prague and Brno.

The acquisition and the analytical data processing was
performed by using S.A.M. system. The system is
constituted by an integrated architecture of analytical
procedures which allow a complete description of the
shape in two-dimensional objects. For this work, mainly
the section dedicated to the description of open curves
using the trigonometric interpolation according to Fourier
polynomial was used (Ponce Delgino et al. 1990, 1991,
1997).

The Fourier harmonic analysis, based on the
trigonometric polynomial, involves the use, as the
dependent variable, of a series of distance values, the

FIGURE 1. A male and a female incisura sample; the points used for the positioning (a and d) and the segment adopted for dimensional normalization (a – b) are reported. The examined traits were the latero-superior (a – c) and the latero-inferior (a – d) rami.

FIGURE 2. Case of clearly male morphology (above) and case of female-like male morphology before and after dimensional normalization; Fourier spectra obtained for: a) latero-inferior rami, b) latero-superior rami.
independent variable being the progressive sum of the adopted equiangular steps over the interval 0–2π.

The result is Fourier sine/cosine coefficients for a number of sinusoidal 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 (Lestrel 1997).

The coefficients of these harmonics are calculated in increasing order corresponding to the period of the sinusoidal contributors, so they are orthogonal or statistically independent of one another (Davis 1986).

According to many authors (Lestrel 1974, 1997, Jacobsbagen 1982, Johnson et al. 1986, O'Higgins, Williams 1987, Diaz et al. 1990, Massahi et al. 1992) this is an extremely powerful procedure which can give 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 superimpositions of single sinusoidal contributors or of partial additions of subsets of these contributors establishing in this way their contribution in determining the studied shape.

The result of the harmonic analysis is typically represented by the Fourier spectrum; a bar graph where, for all the harmonic contributors disposed in a rising order from left to right, the sine and cosine coefficients with positive values (up) and negative values (down) are reported.

In the present study for each os coxae the silhouette of the incisura ischiadica was first obtained by optical projection and by illuminating the incisura by an extended and sufficiently distant light source (Figures 3, 4); then the incisura was considered along the line drawn between the spina ischiadica and the spina ilica posterior inferior till the point where the latero-superior segment of the incisura meets the extremity of the facies auricularis (points 6, c in Figure 1). The above reference points were placed in a system of orthogonal cartesian axes on the same ordinate value; the profiles were dimensionally normalized with an optical scaling attributing the same value of depth to every one (segments a–b in Figure 1) so as to reduce size influences.

In each profile the latero-superior and the latero-inferior parts (a–c and a–d traits in Figure 1) were examined in an independent way.

For each incisura two separate series of 90 equispaced abscissa values were serially acquired starting from the deepest point of the incisura (point a in Figure 1) up to the
two extremities of the incisura (points c and d in Figure 1). Each series was interpolated by a trigonometric polynomial up to the 44th harmonic defining its coefficient spectrum.

From the coefficient couples sine/cosine defining every sinusoidal component, amplitude and phase values were obtained; in addition the total amplitude sum of all 44 sinusoidal components and the integral of the spectrum (Roughness Factor) were calculated.

The spectra of the mean profiles for the male and the female groups respectively, were also obtained.

Fourier parameters obtained from the description of the incisura were used as variables to perform multivariate discriminant analysis (Wilkinson 1989).

RESULTS

In Figure 2 the original silhouette of an incisura of a clearly male kind and a female-like male one, the profile of the inferior and the superior segments of the incisura after dimensional normalization and the relative Fourier spectra are represented.

In Figure 3 an incisura clearly female and a male-like female one, the profile of the inferior and the superior segments of the incisura after dimensional normalization and the relative Fourier spectra are represented.

In Figure 4, the mean outlines for the male and for the female incisura and the corresponding Fourier spectra showing the mean values of the coefficients for both the incisura traits are reported.

Figure 5 shows the graphic synthesis of some harmonics and of their partial and total sums: main sexual differences can be clearly observed in the superior part of the incisura as has already been observed in an empirical way from the logic analysis of the shape. We can also observe that the curve obtained by adding the first 15 harmonics (Figure 5i) already shows the basic architectural morphology of the profiles; in fact, this strongly reduced subset of harmonics contains more than 80% of the total amplitudes and so the greater part of available morphogenetic (in the analytic sense) information. Considering this, amplitude and phase values of only these sinusoïds were used to perform the multivariate discriminant analysis. The information contained in the remaining harmonics is related to the fine and local smoothing of the profiles; however, none of the components of a higher order than the 15th show an amplitude higher than 1% in respect to the total amplitude sum of all 44 extracted harmonics.

In Table 1 the mean amplitude and phase values are reported for both groups.

The main differences in amplitudes and phases, as expected, are shown by the superior arm of the incisura; the maximum values of the total sum amplitude were obtained for the male latero-inferior ramus; whereas for...
TABLE 1. Fourier data obtained by describing the greatest sciatic notch of the treated sample. Amplitudes of the first 15 harmonics (A01 – A15); Phases of the first 15 harmonics (P01 – P15); Amplitude Sum of all 44 harmonics (SUM); Roughness Factor (RF) (integral of the spectrum).

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<tr>
<th>MALES (N = 97)</th>
<th>FEMALES (N = 98)</th>
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<tr>
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<td>2484 710</td>
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<tr>
<td>A06 6076 1142</td>
<td>2132 56</td>
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<td>A07 5282 1007</td>
<td>1867 529</td>
</tr>
<tr>
<td>A08 4712 875</td>
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<tr>
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<tr>
<td>A12 3306 603</td>
<td>1189 333</td>
</tr>
<tr>
<td>A13 3086 566</td>
<td>1108 309</td>
</tr>
<tr>
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<td>1049 292</td>
</tr>
<tr>
<td>A15 2735 521</td>
<td>992 274</td>
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<td>P02 15.252 5.383</td>
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<td>217.201 12.503</td>
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<tr>
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<tr>
<td><strong>RP</strong> 29.490 6.052</td>
<td>5.271 5.271</td>
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P < 0.005) that means that the selected variables are effective in separating the two groups; additional tests (Wilks's lambda, Hotelling-Lawley trace) give results in agreement with F test.

The sample is large enough to accept, eventually, reduction in efficiency of the criteria of inaccuracy, leading to a more reliable parameter: probability group membership due to deviation from multivariate normal distribution; considering that due to inequity of covariance matrices canonical discriminant functions may not provide maximum separation among groups and the probability of group membership will be distorted, the "leaving one out" method was applied in order to obtain an almost unbiased estimate of the expected actual error rate (Lachenbruch 1975). The percentage of misclassified data cases obtained by applying the "leaving one out" method is shown in Table 2.

The unstandardized coefficients of the obtained linear discriminant functions to be used in the maximum convexity position robustness (Figure 7, upper profile) for separate incisura arms and for both ramus together, are reported in Table 3.

CONCLUSIONS

If comparing the approaches used to evaluate the sex differences of the sacral-ilio sacral segment on the basis of the incisura ischiadica major, we have to remember that the best discriminant function obtained by the dimensional parameters correctly classified only 65% of cases; so the results obtained by using Fourier analysis represent a considerable improvement.

Considering the above reported results one can ask: how can an incisura that resulted male from the metrical point of view and with an experienced naked eye, be correctly attributed to the female group using analytical parameters, whereas an incisura that resulted female from the metrical point of view and with the naked eye, was correctly attributed to the male group using shape analysis?

This could suggest that some shape variations which sometimes escape observation and metrical measurements, can be described, in our case, by variation of Fourier amplitude and phase patterns.

A possible answer to the question could be given by observing the outgroup data as reported in Figure 7. They are not simply morphologically extreme cases as those reported in Figures 2 and 3 (the female-like males and male-like females were attributed to the proper group) but are cases morphologically characterized by modified basic architecture.

This poses the problem of ascertaining basic or invariant morphological features that can help the diagnosis: for example, beside the already known features described by the "ideal shape analysis", another one regarding the latero-superior ramus may be described; more precisely this is related to the placement of maximum convexity of the incisura arms, in position 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 fact the outgroup data cases MB45 and MB32 reported in Figure 7, although their superior arm show recurrent trends (a feature commonly accepted as male), are however characterized by having the maximum convexity of the profile placed rather low, and the same can be said for the MB04 case; this corresponds to a mutual phase arrangement and to an increasing amplitude value characterizing them in a feminine sense.

In FB52, FB59 and FB55 data cases, the upper part of the latero-superior ramus appears to be rather swollen and these data cases are characterized, by amplitude and phase values, in the male sense.

The recurrency of the latero-superior ramus, therefore, in true male morphology, must be accompanied by the allocation of the maximum convexity point in the upper part of the ramus, on the contrary misclassifications can occur.
TABLE 3. Unstandardized discriminant functions coefficients. The used variables are as follows: Amplitudes of the first 15 harmonics (A01-A15); Phases of the first 15 harmonics (P01-P15); Amplitude Sum of all 44 harmonics (SUMS & SUMI for latero-superior and latero-inferior arms respectively); Roughness Factor (RFS & RFI) for the latero-superior and the latero-inferior arms respectively. The F value and D' for each equation are also reported.

<table>
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<th>RAMUS SUPERIOR</th>
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F = 3.501 df = 28.166
F = 16.368 df = 21.173
F = 27.583 df = 14.180

D' = 2.3
D' = 7.9
D' = 8.5

REFERENCES


