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METRIC CHARACTERIZATION AND EVALUATION OF THE DISTINCTIVE MORPHOLOGICAL FEATURES OF THE GREATER SCIATIC NOTCH ON A RECENT ITALIAN SAMPLE OF KNOWN SEX

ABSTRACT: Vladimir Novotný's approach to identifying skeletal sex entails a deep understanding of anatomy in relation to the evolutionary implications and adaptive constraints that determine the differentiation of the pelvic region in humans. Considering the sacroiliac and ischiopubic traits as regions that are evolutionarily and functionally distinct leads to a better understanding of the significance of the pelvis structures in relation to sexual dimorphism. Although optimal diagnosis implies the whole combination of the characters in the two districts, some features of the pelvis, such as those in the ischiopubic district, are more informative. Among the structures of the sacroiliac district, the greater sciatic notch has been widely analyzed, but it is difficult to assess since its size and morphology may vary greatly due to its dependence on two anatomical subsystems. To facilitate the analysis, Vladimir Novotný, in his "ideal shape analysis of form" *formalizes the evaluation of the morphology of the greater sciatic notch by identifying three essential features that define its general architecture: length and proportion of the branches, symmetry of the branches, and recurvate course of the superior ramus of the notch. These three features are visually evaluated and then scored in order to reduce the level of subjectivity of the diagnosis. These features can be quantified through conventional and geometric morphometric procedures. It was therefore verified whether morphometric characterization can detect the information expressed through these three features of the morphology of the notch and whether it may be used for diagnostic purposes. To this end, metrical and morphological characterization of the great sciatic notch was carried out for a series of recent coxal bones from a collection housed at the Istituto di Medicina Legale at Bari University (Italy). A total of 171 isolated coxal bones all belonging to 92 identified adult skeletons (45 males and 47 females) were considered for the study.*

The projective image of the greater sciatic notch contours in the trait was analyzed, from the base of the ischial spine to the top of the piriform tubercle, both as a whole and by separating the anterior and posterior branches.

The sample was initially characterized metrically on the basis of linear and angular measurements, but also by evaluating the development of the branches and the areas underlying them. The data obtained were then used to perform

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multivariate exploratory and discriminant analysis. By using variables extracted from the notch as a whole and separately from the two branches, certain discriminant functions able to correctly sex between 90% and 93% of cases were defined. Overall differences in shape were also visualized by changes between configuration landmarks. The variables that were most effective in the analysis were re-considered and discussed.

KEY WORDS: Sex determination - Greater sciatic notch - Morphometry - Multivariate discriminant analysis - Population data - Southern Italy

INTRODUCTION

Although the human pelvis constitutes the most sexually differentiated skeletal region, its dimorphism can be expressed in complex ways due to the evolutionary and functional constraints that determine its general architecture upon which, moreover, variations are grafted deriving from ontogenetic development and from the natural phenotypic plasticity (Fischer, Mitteroecker 2015, Leong 2006, Gruss, Schmitt 2015, Verbruggen, Nowlan 2017, Wall-Scheffler *et al.* 2020). For this reason, the evaluation of sexual dimorphism of the pelvis is an extensively investigated topic of significant interest in defining the biological profile of ancient and recent human skeletal remains.

As is extensively documented, the metric features of the pelvis or, at least, the complete coxal, allow a high degree of accuracy in the estimation of skeletal sex, with various authors indicating a discriminating efficacy greater than 95% and up to 100% when evaluated on samples of known sex (Brůžek *et al.* 2017, Gómez-Valdés *et al.* 2011, Murail *et al.* 2005, Novotný 1981, 1986, Santos *et al.* 2020, Seidler 1980). Analysis is less effective when conducted on fragmentary pelvises (Blake *et al.* 2018, Genovés 1959, Howells 1965, Patriquin *et al.* 2005), although good levels of correct attribution are also obtained by evaluating partial morphological regions (Rissech, Malgosa 1997, Rogers, Saunders 1994, Schulter-Ellis *et al.* 1983, Steyn, İşcan 2008, Thieme, Schull 1957, Washburn 1948, Yoldi-Chaure, Botella-López 1999).

For a better understanding of the sexual dimorphism of the pelvis it is advisable to consider the sacroiliac and ischiopubic regions as developmentally and functionally differentiated. Indeed, although the entire combination of the features of the coxal is necessary for optimal diagnosis, the features of the ischiopubic region are more informative. Among the structures of the sacroiliac region, the greater sciatic notch (GSN) is one of the most representative and most sexually differentiated features (Brůžek 2002, Caldwell, Moloy 1932, Hager 1996, Letterman 1941, Novotný 1986, Walker 2005). Indeed, it constitutes a hinge region between the sacroiliac region, more constrained by functions relating to locomotion and standing, and the ischiopubic region, more constrained by the functional needs deriving from the evolutionary tendency towards encephalization and, therefore, the gestation and birth of neonates with elevated cranial volumes (Washburn 1960, Novotný 1983, 1986, Ruff 2017). Due to such complex needs, the apparent simplicity of the GSN can vary greatly both in size and shape, making it difficult to assess dimorphism.

For this reason, it has been analysed by numerous authors with a range of morphological-visual techniques including conventional metrics (Alizadeh *et al.* 2012, Brůžek 2002, Dibennardo, Taylor 1983, Gómez-Valdés *et al.* 2012, Jovanovic, Zivanovic 1965, Kalsey *et al.* 2011, Krogman 1962, Krogman, İşcan 1986, Patriquin *et al.* 2005, Singh, Potturi 1978, Walker 2005), landmark-based morphometry and contour analysis (Novotný *et al.* 1996, Steyn *et al.* 2004, Takahashi 2006, Vacca *et al.* 1997, 2007). Such techniques reach, in certain cases, levels of high efficacy and may be used for diagnostic purposes.

In the field of visual assessment of GSN morphology, one of the most formalized and effective analysis techniques is that developed by Novotný (1981, 1986) and subsequently re-proposed by Brůžek (2002). According to this approach, it is first necessary to define and standardize observation criteria in order to reduce levels of subjectivity in diagnosis; subsequently, the various morphology components of the GSN are analysed and evaluated separately, attributing a score to each that then contributes to the development of a final diagnostic score.

Fundamentally, three aspects are considered: proportion of the length between the anterior and posterior branch of the GSN, symmetry between branches and recurvate course of the posterior branch.

Ideally, in female morphologies, the equally long branches diverge symmetrically, and the posterior branch is not recurvate. On the contrary, in male morphology, the two branches, which differ in length, diverge asymmetrically and the posterior branch tends to be recurvate (Novotný 1981).

Although the discriminant efficacy obtained through a formal evaluation of such features may be reasonably high (Novotný 1986, Brůžek 2002), it requires a high level of experience and is in any case subjective, particularly in the evaluation of intermediate morphologies.

The same features were also analysed metrically. Various authors report observations based on the relationship between the dimensions of the anterior and posterior section of the "chord" of the GSN (Davivongs 1963, Lazorthes, Lhez 1939, Letterman 1941, MacLaughlin, Bruce 1985, 1986, Novotný 1986, Palfrey 1974, Segebarth-Orban 1980, Taylor, Dibennardo 1984), of the depth and of the breadth expressed as a diameter (Day, Pitcher-Wilmott 1975, Jovanovic, Zivanovic 1965), or as an angle between the branches (Gómez-Valdés *et al.* 2012, Hanna, Washburn 1953, Kalsey *et al.* 2011, Singh, Potturi 1978, Takahashi 2006).

Other features such as the length of the branches, the area under the branches and its fractions, or the subdivision of the angle that describes the breadth in the anterior and posterior portion are less considered, possibly because they are more complex to detect in the field with traditional sliding and coordinate callipers. In reality, even these features may be easily quantified through basic procedures of conventional and geometric morphometry, with instrumentation available in every anthropometric laboratory and with open-source image processing software. It was therefore verified whether morphometric characterization can detect the information expressed by these features of GSN morphology and whether it may be used for diagnostic purposes.

To this end, metrical characterization of the GSN was carried out on a recent sample from the Apulia region in southern Italy. The sample was initially characterized metrically, and the data obtained were used to perform multivariate exploratory and discriminant analysis. Overall differences in shape were also analysed and visualized through changes in configuration landmarks. The results of metric and morphometric characterization were also discussed in relation to the "ideal shape analysis of form" as proposed by Novotný (1981, 1983, 1986).

MATERIALS

A series of 92 skeletons (45 male and 47 female) of documented sex and age presenting a total of 171 isolated coxal bones was available for study. The collection is housed at the Istituto di Medicina Legale, University of Bari (Italy). The remains belonged to adult subjects with dates of death ranging from the 1960s and 1970s and with ages at death ranging from 24–90 years. Bones showing gross evidence of pathological conditions were excluded from the study. The left bones were considered for analysis and the right coxal was used (4 out of 45 for the male sample only) when the left was not available. The sample had been the subject of previous studies on sexual dimorphism. On the same collection, metric characterization of the coxal bone was carried out with the aim of determining sex by means of discriminant multivariate analysis (Vacca, Di Vella 2012).

The original metric data of the sample of Czech and German origin extracted and tested by Novotný regarding various modifications of the ischiopubic index and of the indices of GSN were used for comparative purposes (Novotný 1986).

METHODS

Positioning and contour detection of the Greater Sciatic Notch

With the aim of characterizing the GSN metrically, an updated version of the technique developed by Hanna and Washburn (1953) was adopted, modified by Novotný (1981) and re-proposed by Brůžek (2002). Variants of the same technique have been proposed by other authors for both conventional and geometric morphometrics (Gomez-Valdés *et al.* 2012, Listi, Bassett 2006, Steyn *et al.* 2004, Takahashi 2006).

In the Novotný technique, the contour of the GSN is obtained by placing the latero-dorsal iliac surface of the hip bone on photosensitive paper and exposing it to a light source. In this study, the bones were placed on the photographic stand plane with their internal surface facing upwards. In this position, the contour of the GSN is approximately parallel to the surface. In order to obtain the maximum projective diameters, the coxal was inclined so as to place three reference points on the horizontal plane: the piriform tubercle, the base of the ischial spine and the deepest point of the GSN. The orientation of the points on the plane was verified by a self-levelling crossline laser.

The bones were then photographed on a black background with a ruler placed near the GSN edge following standards for morphometric data acquisition (Loy, Slice 2010). The focal plane was placed horizontally and centred on the ventral aspect of the GSN; possible parallax errors were also checked by means of reference grids. Image capture was performed with a Nikon D5000 digital camera equipped with an AF-S DX Nikkor 18–105 mm standard zoom lens. The camera was placed at a fixed distance (75 cm) from the bone and at a fixed focal point. Considering the size and characteristics of the structure under analysis, a standard quality photographic format (JPG, 2560×1920, 300ppi) was considered sufficient for the purposes of the research. An image pre-treatment phase was necessary before data extraction. The photographs were standardized in terms of their position and orientation.

For the definition of the contour under analysis, the criterion proposed by Genovés (1959) and adopted by Novotný (1981, 1986) was followed; see also Santos *et al.* (2020) for various proposals on measuring the GSN.

The profile considered (*Figure 1*) is defined from the top of the piriform tubercle (A), to the base of the ischial spine (B). In case of its absence, the tubercle is substituted by the point of contact between the upper edge of the GSN and the end of the *facies auricularis*. Based on these two points, which define the distance between the antero-inferior and postero-superior ends of the notch, the photograph was rotated so as to bring the two points onto the same horizontal axis. The area between the edge of the notch and the segment ($\overline{AB}$) was then selected using a suitable threshold value, obtaining a projective image of the GSN contour.

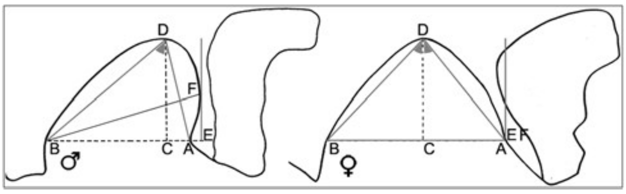

FIGURE 1: The greater sciatic notch, standard positioning and reference points used to define the boundaries for metric and shape analysis on male and female morphology. A, top of piriform tubercle; B, base of the ischial spine; C, projection of the apex (D) on the width $\overline{AB}$; E, projection of the rearmost point of the contour on the extension of the width $\overline{AB}$; F, variable ending point of the Feret diameter; $\overline{CD}$, depth of the notch; $\overline{AC}$ posterior part of the width; $\overline{CB}$, anterior part of the width; $\overline{BE}$, maximum projective diameter parallel to the width $\overline{AB}$; $\overline{BF}$, Feret diameter.

The segment between the deepest point of the notch, the apex of the GSN (D), and its projection (C) on the width ($\overline{AB}$) separates the anterior and posterior segments and constitutes the depth ($\overline{DC}$). Considering that the anterior and posterior tracts can be considered anatomically and functionally distinct (Novotný 1986), the notch was analysed as a whole, as well as the anterior and posterior tract separately.

Metric Data Extraction

The bitmapped black and white images of the GSN were imported and analysed using ImageJ software (Rasband 1997–2018) and a macro for batch processing was developed and used for measurements. The equally-scaled images were binarized, cropped to standardized positions and the boundaries of the GSN were selected for the extraction of metric data. The primary measurements (area, perimeter, diameter, angles) were used to calculate additional parameters (*Table 1*).

According to Novotný (1981), one of the determining elements for sexually differentiating the GSN is constituted by the recurvate shape of the posterior branch. Among the parameters employed, this feature may be identified by Feret diameter, corresponding to the longest distance between any two points along the contour. In the case of the present work, the Feret diameter joins the base of the ischial spine (*Figure 1*, point B) with the farthest point on the posterior contour of the GSN (*Figure 1*, point F). The position of this point may vary along the contour. In the female "ideal form" the farthest point from the base of the ischial spine is the top of piriform tubercle (*Figure 1*, point A), in which case the Feret diameter coincides with the T.Width ($\overline{AB}$) and the Feret angle is equal to zero. In male morphologies, the farthest point may not coincide with the top of piriform tubercle but may be placed at various points along the contour. In such cases the Feret diameter does not coincide with the T.Width ($\overline{AB}$) and the angle formed by the Feret diameter is greater than zero, registering the presence and position of a recurvate trend along the contour. The same characteristic could be evaluated by the difference between the T.Width ($\overline{AB}$), and the T.Width.Max ($\overline{BE}$). The two measurements in females tend to be very similar whereas in males, the first (T.Width, $\overline{AB}$) tends to be less than the latter.

Evaluation of measurement errors

Twenty randomly selected cases were processed and measured again following an adequate time interval (Buikstra, Ubelaker 1994). Eight primary

TABLE 1: List of measurements used to metrically characterize the Greater Sciatic Notch. Letters (A, B, C, D, E, F) refer to points illustrated in Figure 1. *Measures used for the Technical Measurement Error.

Abbreviations	Definition
	Total notch
T.Area	Total area; enclosed by the full notch contour and the width $\overline{AB}$
T.Width	Total notch width; distance $\overline{AB}$
T.Width.Max	Total maximum width ($\overline{BE}$) parallel to the width ($\overline{AB}$), i.e. the width of the total bounding box
T.Ang.D	Total angle $A\hat{D}C$; greater sciatic notch angle
T.Feret.Diam	Total Feret diameter; from point B to the farthest point on the posterior ramus (F)
T.Feret.Angle	Total Feret angle; angle between Feret diameter and the width $\overline{AB}$
T.Depth	Total depth; distance $\overline{DC}$, i.e. the height of the total bounding box*
T.Length	Length of the total contour between points A and B*
	Anterior ramus
A.Area	Anterior area; enclosed by the ramus and segments $\overline{BC}$ and $\overline{CD}$*
A.Width	Anterior width; segment ($\overline{BC}$) of the total width ($\overline{AB}$)*
A.Hyp	Hypotenuse of the anterior triangle; distance $\overline{BD}$
A.Angle	Anterior angle $B\hat{D}C$*
A.Tr.Area	Anterior triangle (BCD) area
A.R.H.Area	Area enclosed by the anterior ramus and the hypotenuse $\overline{BD}$
A.Length	Length of the anterior ramus between points B and D*
	Posterior ramus
P.Area	Posterior area; enclosed by the ramus and the segments $\overline{AC}$ and $\overline{DC}$*
P.Width	Posterior width; segment ($\overline{AC}$) of the total width ($\overline{AB}$)*
P.Width.Max	Posterior maximum diameter ($\overline{CE}$) parallel to the width ($\overline{AB}$); i.e. the width of the posterior bounding box
P.Hyp	Hypotenuse of the posterior triangle; distance ($\overline{AD}$)
P.Angle	Posterior angle $A\hat{D}C$*
P.Tr.Area	Posterior triangle (ACD) area
P.R.H.Area	Area enclosed by the posterior ramus and the hypotenuse $\overline{AD}$
P.Length	Length of the posterior ramus between points A and D*

measurements (*in *Table 1*) obtained for the anterior and posterior ramus separately and for the entire GSN were considered in order to evaluate the measurement error. The two series were then used to calculate intra-observer technical measurement error (TEM) (Lewis 1999, Perini *et al.* 2005, Ulijaszek, Kerr 1999). The extent of the differences between the two series of measurements was also evaluated using a paired sample t-test.

Descriptive and comparative statistics

Descriptive statistics were obtained for the male and female groups to characterize them metrically. Normal distribution was evaluated using the Kolmogorov-Smirnov test and the F-test was used for evaluating the equality of variance.

For each variable, a comparison between the means of the two sexes was carried out by a two-sample t-test. The comparison between sexes was, therefore, carried out by comparing the variables describing the entire notch and, separately, the variables extracted from the anterior and posterior contours. A comparison was also made between anterior and posterior branches of the same sex for the evaluation of their symmetry.

Discriminant analysis

Both stepwise and direct discriminant analyses were performed in order to define any functions that may prove useful in the determination of skeletal sex. The functions were first selected by identifying the highest discrimination between the two groups, independent of the number of variables used. Subsequently, functions based on a limited number of variables that were able to better discriminate between the two groups were defined.

Although discriminant analysis is considered to be reasonably robust in terms of deviations from the normality (Lachenbruch 1975), multivariate normality was evaluated (Korkmaz *et al.* 2014) and combinations of seriously non-normal variables were excluded from analysis.

Considering the small sample size, it was not possible to use both a training set and a test set. Nevertheless, for an unbiased error estimates, the leave-one-out method was applied removing and reclassifying one case at a time from the entire sample, calculating normal attribution errors and jack-knife errors (Lachenbruch 1975). SYSTAT software (Wilkinson 1989; Systat 2007) and SPSS (IBM 2016) were used to carry out statistical analysis.

Geometric morphometrics

In order to evaluate shape differences, a landmark-based geometric morphometrics analysis was performed (Bookstein 1998, Rohlf, Marcus 1993, O'Higgins 2000, Adams *et al.* 2004, Slice 2005).

The same points used to define the outline of the notch (*Figure 1*), i.e. those points corresponding to: (A) the top of the piriform tubercle, (B) the base of the ischial spine, (C) the point of separation of the anterior and posterior section, (D) the deepest point of the boundary, were automatically detected with a macro in ImageJ and defined as landmarks. Considering that the information contained in the traits of the boundaries between the landmarks cannot be neglected, eighteen semi-landmarks (Bookstein 1997), nine for the anterior branch and nine for the posterior branch, were also identified at equiangular steps on the edge of the GSN according a radius vector originating from point C (*Figure 2*).

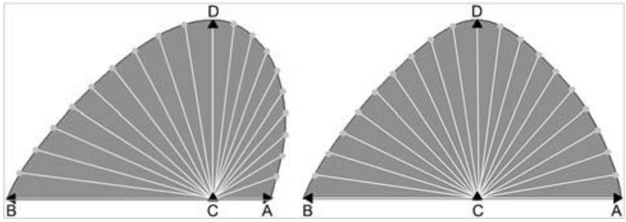

FIGURE 2: Location of landmarks and semi-landmarks used to evaluate the sexually differentiated shape of the GSN. Landmarks (black triangles) refer to (A) top of the piriform tubercle, (B) base of the ischial spine, (C) point separating anterior and posterior part of the width, (D) deepest point of the GSN. Nine semi-landmarks for the anterior ramus and nine for the posterior ramus (grey points) were collected on the edge of the GSN at equiangular steps according to a radius vector originating from (C).

Considering that possible variations in the data and in contour extraction can be introduced only in the orientation and segmentation phases of the notch and that for this phase of procedures an evaluation of measurement errors had already been carried out, it was not considered necessary to carry out a further error evaluation.

The raw coordinates (landmarks and sliding semi-landmarks) were subjected to Generalized Procrustes Superimposition, thus removing all information not relating to shape variation, to align specimens and to estimate average shapes (Rohlf, Slice 1990, Dryden, Mardia 1998). Relative warps were computed by performing a Principal Component Analysis on the aligned landmark coordinates of each sample and thin-plate spline deformations were obtained in order to visualize shape differences between reference forms (Bookstein 1989, 1991, Dryden, Mardia 1998, Rohlf 1993). TPS (Rohlf 2004, 2015) and PAST software (Hammer *et al.* 2001) were used for analysis.

Finally, the scores obtained from principal component analysis were used as shape variables to perform multivariate discriminant analysis, verifying the effectiveness of the extracted structures in sexual differentiation (Rohlf 1995).

RESULTS AND DISCUSSION

Descriptive and comparative statistics

Intra-observer error evaluated using Technical Error of Measurements (TEM) on twenty randomly selected cases showed an acceptable level of uncertainty. Low

TABLE 2: Descriptive and comparative statistics of the Greater Sciatic Notch measurements (left side). Linear measures, mm; area measures, mm^2; angles, degree. ^Unequal variances t-test: P.Width.Max, df= 76.7; T.Feret.Angle, df = 57.3. ns p>0.05, * p<0.05, ** p<0.01,*** p<0.001.

Variable	Male – n = 45				Female – n = 47				Mean Diff.	t(90)p
	Min	Max	Mean	SD	Min	Max	Mean	SD		
Total notch										
T.Area	427.5	984.9	667.2	130.3	488.6	957.9	738.3	128.1	-71.1	-2.63**
T.Width	33.8	50.2	40.7	3.9	37.7	60.9	46.1	5.4	-5.4	-5.44***
T.Width.Max	36.0	50.6	42.0	3.7	37.7	60.8	46.3	5.3	-4.3	-4.49***
T.Ang.D	60.7	92.1	77.0	7.3	74.0	102.0	88.1	5.7	-11.1	-8.15***
T.Feret.Diam	36.8	52.1	43.3	3.6	38.0	60.8	46.4	5.3	-3.1	-3.27**
T.Feret.Angle^	0.4	32.7	17.8	8.0	0.0	13.2	1.7	3.2	16.1	12.53***
T.Depth	16.1	29.7	23.4	3.2	17.6	27.7	23.4	2.2	0.00	-0.01 ns
T.Length	57.6	86.4	71.7	6.5	60.3	83.8	73.1	6.3	-1.4	-1.00 ns
Anterior ramus										
A.Area	253.7	559.2	418.4	73.9	259.3	532.6	375.5	63.4	42.9	2.98**
A.Width	21.9	40.0	29.2	3.6	17.5	34.9	25.0	3.9	4.2	5.34***
A.Hyp	30.6	46.5	37.6	3.4	28.6	42.5	34.4	3.2	3.2	4.60***
A.Angle	36.8	63.2	51.2	5.2	34.7	60.3	46.7	5.1	4.5	4.20***
A.Tr.Area	220.3	474.1	341.9	61.0	198.1	422.7	293.3	54.1	48.6	4.05***
A.R.H.Area	32.0	136.3	76.4	22.8	47.6	116.1	82.2	17.6	-5.8	-1.37 ns
A.Length	32.3	49.7	40.1	3.6	30.9	45.4	37.2	3.2	2.9	4.08***
Posterior ramus										
P.Area	121.6	440.6	248.9	75.1	170.9	527.0	362.1	85.9	-113.2	-6.72***
P.Width	2.0	19.9	11.5	3.9	8.9	31.9	21.1	4.8	-9.6	-10.52***
P.Width.Max^	7.8	20.0	12.8	2.8	11.3	31.9	21.2	4.6	-8.4	-10.76***
P.Hyp	18.4	35.4	26.3	3.9	20.7	40.3	31.7	4.4	-5.4	-6.21***
P.Angle	5.7	39.0	25.8	7.1	25.4	52.4	41.4	5.5	-15.6	-11.86***
P.Tr.Area	20.6	291.0	137.7	59.2	83.0	392.6	250.4	71.2	-112.7	-8.24***
P.R.H.Area	67.3	174.2	111.2	24.4	67.5	177.5	111.7	23.9	-0.5	-0.09 ns
P.Length	23.1	40.6	31.7	4.0	26.5	44.0	35.9	4.3	-4.2	-4.93***

TEM and relative TEM values, less than 5%, with a maximum score (3.4%) for the measure of the anterior area (A.Area) and the reliability coefficient (R) consistently higher than 0.95 indicate an acceptable level of uncertainty and a reliable measurement (Ulijaszek, Kerr 1999, Goto, Mascie-Taylor 2007). In addition, based on paired t-test results, the two series of repeated measurements do not differ significantly ($p>0.05$).

According to the Shapiro-Wilk test, the normal distribution hypothesis may not be excluded for any of the variables analysed except for the posterior angle of the male sample (P. Angle, $W = 0.919$, $p < 0.05$) and for the T.Feret.Angle ($W = 0.605$, $p < 0.05$) of the female sample. Variance may generally be assumed to be equal, or not too dissimilar, with the exception of the T.Feret.Angle ($F_{(1,90)} = 280.8$, $p<0.05$) and the P.Width.Max ($F_{(1,90)} = 120.4$, $p<0.05$).

Descriptive statistics and comparative t-test between the sexes both for the GSN as a whole and separately for the anterior and posterior tract are reported in *Table 2*.

Comparison between the sexes of the GSN as a whole

If the GSN as a whole is considered, the values obtained for the female sample are greater than those obtained for the male sample, with the exception of the Feret angle. In females, the Feret diameter tends to coincide with both T.Width and T.Width.Max (approximately 46mm). In males, instead, it is greater (43.3mm) than both the T.Width (40.7mm) and T.Width.Max (42.0mm). As a result, the Feret diameter in females represents a significantly smaller angle (1.7°) than in males (17.8°). Further significant differences are noted for the T.Area, for T.Ang.D and for the T.Width. Specifically, the opening of the GSN (T.Ang.D) in females (approximately 88°) is around 11° wider than in the male notches (approximately 77°). The differences in depth (T.Depth) are not significant. Indeed, the measured value is, on average, identical for the two sexes (23.4 mm). The differences in total length (T.Length) are also not significant, a typical case in which metric data is not able to detect obvious differences in shape.

Comparison of the sexes through separate anterior and posterior tract analysis

The differences between the two sexes are highly significant when comparing the anterior and posterior segments separately, with the exception of the areas between the contours and the respective "chords" (A.R.H.Area for the anterior region and P.R.H.Area for the posterior). In a comparison between the anterior branches, the values of the male sample are prevalent while in the comparison between posterior branches, the values of the female sample are prevalent as evident from the average differences. The major differences, however, are found in the comparison between the posterior branches. The absolute mean difference between male and female posterior widths (P.Width Mean Diff. = 9.6mm) is greater than twice the difference between the anterior widths (A.Width Mean Diff. = 4.2mm). The difference between the angles is approximately three times greater in the posterior branch (P.Angle Mean Diff. = 15.6°) than the differences in the anterior branch (A.Angle Mean Diff. = 4.5°). The differences in length are also slightly greater for the posterior branch (P.Length Mean Diff. = 4.2mm, A.Length Mean Diff. = 2.9mm). Therefore, the dimensions of the anterior branch are larger in males while the dimensions of the posterior branch are larger and with higher differential values in females.

Comparison between anterior and posterior branches within the sexes for the evaluation of symmetries

If differences are evaluated by comparing the values of the anterior branch with the values of the posterior branch of the same sex, it is possible to evaluate the extent of the asymmetries between them (*Table 3*).

There are significant average differences between the anterior and posterior ramus for all measurements in males, which are therefore asymmetric for all measurements considered. Likewise, the differences in females are significant for linear and angular variables for which they are, therefore, asymmetric. Conversely, they are symmetrical for the comparison between the anterior and posterior areas (A.Area/P.Area, $p=0.254$) and, to a lesser extent, for the length of the branches (A.Length/P.Length), whose significance level is just below the rejection threshold ($p=0.043$).

The greater male asymmetry is also evident from the absolute values of the differences between anterior and posterior measurements which are greater than in females (*Table 3*). The values of the anterior segment are, in both sexes, always prevalent, with the exception of the area between the contour and the hypotenuse (A.R.H.Area/P.R.H.Area) due to the greater curvature of the posterior branch in both males and females.

A further element of differentiation between the two sexes is represented by the difference in the posterior branch between the width (P.Width) and the maximum width (P.Width.Max) (*Table 2*). In males, the P.Width.Max is greater than the P.Width by about 1.3mm and this difference is highly significant ($t = 5.9$, $p<0.001$)

while in females, this difference, although significant, is only 0.2 mm (t = 2.4, p=0.018). This difference originates from the shape of the male ramus which in the terminal part tends to assume a recurvate trend for which the top of piriform tubercle (point A in *Figure 1*) is less distant from the axis separating the anterior from the posterior part than the point of maximum convexity of the same branch (point E, *Figure 1*).

Commenting on the results reported, bearing in mind the morphological features employed by Novotný (1981, 1986) in order to make the visual diagnosis of the GSN, it may be said that, in the sample examined:

- the proportion between the branches is significantly different in the two sexes, based on the comparison between the anterior ($\overline{BC}$) and posterior ($\overline{AC}$) segment of the T.Width ($\overline{AB}$) or through the comparison of other variables such as the angles to the vertex (A.Angle and P.Angle);
- the asymmetry, evaluated by the differences between the anterior and posterior branches in the same sex, is significantly greater in male notch;
- the course of the posterior contour is differentiated in the two sexes if we consider the differences between the diameters (T.Width and T.Width.Max) and the Feret diameter (T. Feret.Diam), greater in males than in females.

Therefore, the three conditions considered in the visual diagnosis of Novotný can be considered metrically evaluated.

Multivariate Discriminant Analysis

The discriminant functions selected by looking for the highest discrimination between the two groups are reported in *Table 4.* Some functions with less discriminant power are also reported in order to evaluate the contribution of variables commonly discussed for diagnostic purposes. For each equation, the level of correct attribution, the coefficients of the function and the related statistical evaluators are reported. The standardized canonical discriminant coefficients are also given to highlight the weight of each variable in the functions.

The highest discriminant values were obtained from the variables extracted from the posterior portion of the GSN. Comparable results are also obtained from the combination of variables of the anterior and posterior tracts and of the GSN considered as a whole. Significantly lower correct attribution values are obtained from the variables extracted from the anterior portion of the GSN.

The function presenting the highest level of correct attribution consists of a combination of only two variables from the posterior region of the GSN, the maximum width (P.Width.Max) and the ramus length (P.Length), for which a correct attribution of 93.5% is obtained (F.1). Slightly lower yet comparable (92.4%) are the correct attribution values obtained using the posterior width (P.Width) and the distance between the posterior-inferior iliac spine and the apex of the GSN (P.Hyp) corresponding to the hypotenuse of the posterior triangle (F.2); the same result is obtained by associating the posterior width (P.Width) to the posterior area (P.Area) or the area of the posterior triangle (P.Tr.Area). The posterior angle alone is able to correctly attribute 91.3% of cases (F.3). Using the posterior width (P.Width) and the branch length (P.Length), the correct attribution results as 90.2% (F.4). The posterior width (P.Width) is therefore less effective than the maximum posterior width (P.Width.Max).

The discriminant levels obtained from the variables extracted from the anterior region of the GSN are

TABLE 3: Comparison between anterior and posterior branches within the sexes for the evaluation of symmetries.

Variables	Male – n = 45		Female – n = 47	
	Mean diff.	t(44)p	Mean diff.	t(46)p
A.Area / P.Area	169.5	15.8***	13.4	1.1 ns
A.Width / P.Width	17.7	18.6***	3.9	4.0***
A.Hyp / P.Hyp	11.3	18.7***	2.7	3.9***
A.Angle / P.Angle	25.4	16.9***	5.3	4.0***
A.Tr.area / P.Tr.Area	204.2	19.0***	42.9	3.8***
A.R.H.Area / P.R.H.Area	-34.8	-10.4***	-29.5	-10.3***
A.Length / P.Length	8.4	14.9***	1.3	2.1*

significantly worse. The highest value (73.9%), is obtained from the combination of 3 variables, the area of the anterior triangle (A.Tr.Area), the width (A.Width) and the area (A.Area) (F.5). None of the remaining variables, i.e. the anterior angle (A.Angle), branch length (A.Length) or depth (T.Depth) increases the discriminant value. The discriminant efficacy of the anterior tract is therefore approximately 20% less than the posterior tract.

Correct attribution levels obtained using total GSN values are also lower than those obtained from the posterior tract alone. The combination of 5 variables (T.Feret.Diam, T.Length, T.Width, T.Area, T.Width.Max) correctly attributes 85.9% of cases (F.6) confirming that, in order to optimize diagnosis, the anterior and posterior tracts must be evaluated separately.

Considering the combination of both total and partial values of the GSN, the highest correct attribution percentage obtained from the combination of 3 variables (F.7), namely the depth (T.Depth), anterior width (A.Width) and posterior width (P.width), is comparable (92.4%) but not higher than the value obtained from the posterior region alone.

It is evident that, across all functions, variables relating to sexual differences associated with the widening of the GSN, in particular of the posterior tract which is significantly greater in females, are decisive, whether evaluated through linear measurements, through angular values or through area values.

The differences described are, as expected, largely congruent with that reported by a number of authors from the outset of morphological observations and metric evaluations of the sexual dimorphism of the pelvis (see Introduction for references). The comparison with similar results reported in the literature is, however, made difficult by the heterogeneity of the techniques adopted. Furthermore, data concerning the GSN are often used in association with other measurements of the pelvis so as to maximize the effectiveness of diagnosis.

According to Washburn (1948) the characteristics of the ischium and pubis, in combination with those of the GSN, can correctly classify more than 95% of cases (Hanna, Washburn 1953), yet without the contribution of the ischiopubic region, the level of correct attribution stands at only 75%. A similar value (75%) is obtained by Davivongs (1963) using the posterior length of the GSN in an Australian sample.

Arsuaga and Carretero (1994) report a correct attribution rate of approximately 78% using three GSN characteristics on a sample from the Coimbra collection.

High values of correct attribution are obtained by Patriquin *et al.* (2005) from combinations of variables extracted from the integer coxal yet the value does not exceed 78% when only width and height of the GSN are considered.

According to Novak *et al.* (2012) the ratio of length to width of the sciatic notch correctly classifies 76.3% of cases and is less valuable in determining sex than the morphological scores.

Novotný considers the width of the posterior tract of the GSN in combination with the Ischion and Pubis length as well as the height of the GSN obtained according to Sauter and Privat (1955), in order to define discriminant functions capable of fully determining the sexes in a sample of known origin (Novotný 1981, 1986, Ferembach *et al.* 1980). For the GSN alone, Novotný, using all dimensions (6 variables including height measured according to Sauter and Privat, 1955), reports a correct attribution rate of 92% for a Central European sample of determined sex. Using the original data and the same variables detected by Novotný (1986) for the GSN of the Central European sample, it was possible to replicate the classic discriminant analysis obtaining the values reported by the Author (92% of cross-validated total correct attribution, 91.7% males, 92.4% females). Surprisingly, replicating the analysis with the stepwise variable selection method, the same result is obtained (92.6% of cross-validated total correct attribution, 92.7% males, 92.4% females) but with only 3 variables (P.Width, A.Width, T.Ang.D). The height (T.Depth), the total width (T.Width) and the height of the GSN, measured following Sauter and Privat (1955), were irrelevant and excluded from analysis. Comparable results are obtained from the same data (91.3% of cross-validated total correct attribution, 92.7% males, 89.9% females), using the variables of function no.7 (*Table 4*) defined on the Italian sample analysed in the present work, i.e. the anterior width (A.Width), posterior width (P.Width) and GSN depth (T.Depth).

The convergence between the results obtained from the analysis of the Italian sample and the results obtained for the Central European sample, further indicate that the relative dimensions and proportions of the anterior and posterior tracts of the GSN are sufficiently differentiated so as to allow reliable sex diagnosis, at least for the population groups on which they were tested.

Geometric morphometry

A limitation of the conventional morphometric approach is the difficulty of detecting variations in

TABLE 4: Multivariate discriminant analysis, canonical discriminant functions for Greater Sciatic Notch dimensions. Unstandardized (U.Coeff) and standardized (S.Coeff) coefficients, constant (Const.), correctly classified % of males and females (M/F Corr. class.%), total correctly classified % (Tot.Corr.class.%), Male and Female centroids (M/F Centroids), sectioning point (Sect.point). Leave-one-out method for cross validation is used.

Function n.	Variables					Const.	M/F Corr. class.%	Tot.Corr. class.%	M/F Centroids	Sect. point	Eigenv.	Wilk's Λ	F-ratio df
F.1	P.Width.max	P.Length											
U.Coeff	0.450	-0.259				1.053	95.6/91.5	93.5	-1.387/1.328	-0.029	1.883	0.347	83.8***
S.Coeff.	1.714	-1.064											2, 89
F.2	P.Width	P.Hyp											
U.Coeff	0.399	-0.259				0.485	91.1/93.6	92.4	-1.290/1.235	-0.028	1.565	0.380	72,5***
S.Coeff.	1.714	-1.064											2; 89
F.3	P.Angle												
U.Coeff	0.158					-5.342	88.9/93.6	91.3	-1.264/1.211	-0.027	1.565	0.390	140.8***
S.Coeff.	1.00												1, 90
F.4	P.Width	P.Length											
U.Coeff	0.348	-0.196				0.925	91.1/89.4	90.2	-1.281/1.227	-0.027	1.607	0.384	71.5***
S.Coeff.	1.521	-0.807											2, 89
F.5	A.Tr.Area	A.Width	A.Area										
U.Coeff	0.029	0.172	-0.022			-5.174	73.3/74.5	73.9	0.612/-0.586	0.013	0.366	0.732	10.7***
S.Coeff.	1.694	0.644	-1.529										3, 88
F.6	T.Feret.Diam	T.Length	T.Width	T.Area	T.Width.Max								
U.Coeff	0.873	0.392	0.253	-0.018	-1.246	-11.08	77.8/93.6	85.9	1.050/-1.005	0.023	1.079	0.481	18.6***
S.Coeff.	3.972	2.519	1.204	-2.282	-5.764								5, 86
F.7	T.Depth	A.Width	P.Width										
U.Coeff	0.214	0.024	-0.258			-1.440	93.3/91.5	92.4	1.314/-1.258	0.028	1.689	0.372	49.5***
S.Coeff.	0.583	0.089	-1.127										3, 88

shape, even when such variations are evident, as in the case of the GSN and, in particular, of its posterior tract. Typically, features such as the length of the contour, metrically not significant in the comparison between the sexes, perceptually appear instead to be very different shapes. To highlight such differences, it is necessary to remove size information by means of dimensional normalization and position standardization procedures.

Figure 3 shows the configuration of landmarks, obtained by sampling the contour of the GSN, after superimposition of the raw landmark data by Generalized Procrustes analysis (Rohlf, Slice 1990). Residual information, after the removal of differences in size, position and orientation, refers to the shape. It is evident that, as for metric features, also shape differences are greater for the posterior branch. If the differences in the general architecture of average forms are considered, the female form in the apex region is skewed anteriorly towards the ischio-pubic region with respect to the male form; it is, however, shifted posteriorly in the terminal section of the branch giving rise to the situation of greater symmetry typical of female forms. In the male form the apex is, on the contrary, shifted posteriorly, towards the sacroiliac region, while the end of the branch curves anteriorly, giving rise to the typical masculine recurvate course.

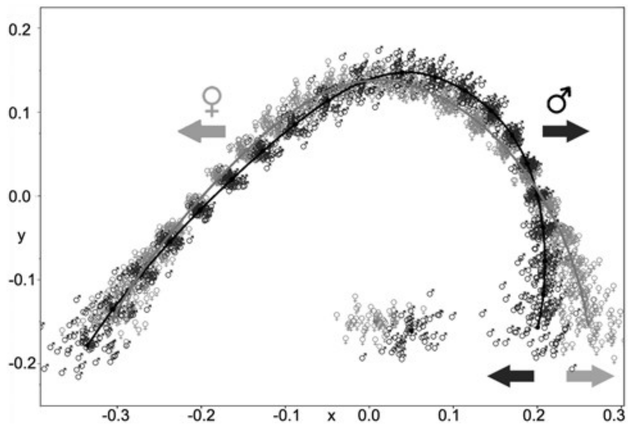

FIGURE 3: Scatter plot of landmark coordinates for male and female configurations in a Generalized Procrustes Superimposition. The average male and female shapes are also superimposed for comparison.

Principal component analysis

Among the components obtained by subjecting the shape coordinates to principal component analysis the first 5 were considered, representing over 99% of the total variance. The graphic display of the distribution of the single scores on the basis of the first two components, in association with the variations of the relative morphospace, is shown in *Figure 4a*. The first component (72.06% of total variance) is mainly associated with the variations in the symmetry between branches. Indeed, the component is positively associated with a greater differentiation of the posterior branch, typical of the male forms, and is, instead, negatively associated with a greater symmetry between branches as typically occurs in the female forms. The second component (22.97% of total variance), also partly modulates the asymmetry between the branches but is also associated with variations in the total opening of the GSN. The third component (2.29% of total variance) modulates the curvature of the posterior branch and the variations in width in the region of the apex.

Due to cross-loadings, it is not possible to clearly identify the precise association between the individual shape coordinates and the components, even after rotation. From vectorial visualization (*Figure 4a, b*) it seems, however, evident that the first component is mainly associated with variations according to the width or, rather, according to the x-coordinates of landmarks in correspondence with the apex and the extremes of the branches, especially the posterior branch. Significantly, the vector relating to the landmark that divides the width of the GSN into anterior and posterior tracts and the vector originating from the terminal point of the posterior branch (points C and A in *Figure 1*) converge in relation to the smaller width of the posterior tract in male forms and diverge in relation to the greater distances in female forms. The second component is instead associated with the variations of the landmarks according to depth and, therefore, according to y-coordinates, determining the proportions between the axes and, in part, their symmetry.

The scores obtained from the first five components used as shape variables in the multivariate discriminant analysis correctly classify 93.5% of cases (cross-validated correctly classified: male = 96.5%, females = 91.5%), confirming the descriptive efficacy of the structures sexually differentiated extracted from the analysis.

The results obtained through geometric morphometry are also only partially comparable with similar results reported in the literature due to the diversity of the descriptive standards adopted.

Using five landmarks on the GSN, Steyn *et al.* (2004) state that, on the base of the shape of the GSN, it is possible to separate black South African males, characterized by a clear male morphology, from both black and white South African females, characterized by female morphology. The shape of white South African males is, instead, highly variable and cannot be distinguished from other groups. According to the authors, this would suggest that the GSN is a good indicator of sex in black South Africans but is not reliable for white South Africans, once again indicating that the diagnostic criteria defined for a specific population group should be applied with caution to other groups.

In the assessment of sexual differences between various morphological regions in a population of black South African individuals, Pretorius *et al.* (2005), using the shape of the GSN, obtained a separation between the sexes with 87.1% of females and 93.1% of males correctly assigned. The greatest sexual differences are attributed to the width of the GSN.

Gómez-Valdés *et al.* (2012) from a relative warp analysis carried out by sampling the GSN with 32 landmarks, demonstrates up to 96.2% of correct attribution by identifying the greatest differences between the sexes in the posterior border.

Veleminska *et al.* (2013) analysing the GSN in Euro-American and Hispanic populations with different methods of geometric morphometry for contours and landmarks, obtain an accuracy of 92% for a pooled sample, suggesting that sex determination based on the shape of the GSN could be population non-specific.

Population variations of the sexual dimorphism of GSN were explored by Kilmer and Garvin (2020) with boundary approximation through elliptical Fourier analysis techniques, obtaining a correct classification of 86.8%.

The diagnostic efficacy of alternative techniques compared to conventional metric techniques was also evaluated using the original data set of Novotný. Using Fourier descriptors (Novotný *et al.* 1993, Vacca *et al.* 1997), and a parabolic interpolation technique to evaluate the symmetry between branches (Novotný *et al.* 1996), correct attribution percentages were obtained of between 92% and 94%.

CONCLUSIONS

The principal aim of the present work is the morphometric characterization of the GSN on a recent sample from the Apulia region in southern Italy. To this

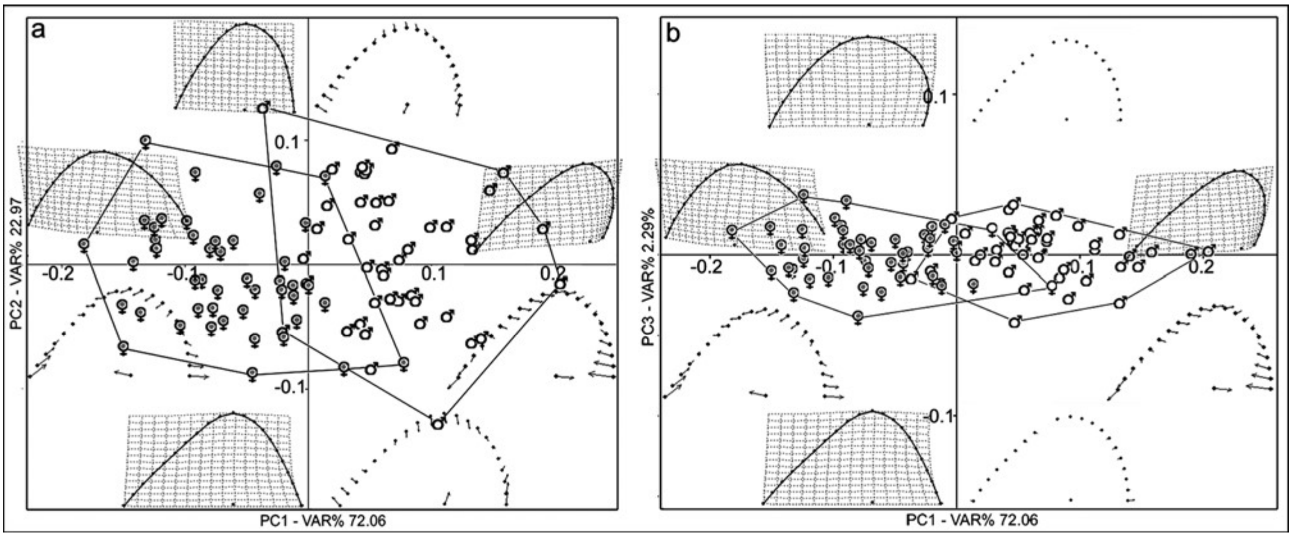

FIGURE 4: Principal component analysis of the GSN and the position of individuals in relation to the first three components is reported. The thin-plate spline transformation grids represent the variation of the morphospace along axes with respect to the shapes of reference (a: PC1, PC2; b: PC1, PC3). The amount and localization of shape differences are also illustrated by the displacement vectors of the landmarks.

end, the work demonstrates how, in this sample, the dimensional and morphological variability of the sexually differentiated GSN is expressed, while verifying whether the information gathered is usable for diagnostic purposes.

In general terms, the morphological and metric evaluation of the GSN, as shown by the observations reported, agrees with that reported by various authors despite the diversity of the standards and techniques adopted. Similarly, the best levels of correct attribution obtained for the sample examined by both conventional and geometric morphometry, consistently between 90% and 93%, align with the highest values reported in the literature for the GSN.

The reported characterization, in addition to increasing the body of knowledge on human variability, also responds to the need to have specific diagnostic elements for a given population. Indeed, although attempts to define criteria applicable to general human variability are significant (Santos *et al.*, 2020), it is reasonable to assume that knowledge of regional variability is, where available, still both essential and beneficial in carrying out reliable diagnosis.

The use of visual and metric diagnostic criteria inevitably conflicts with the attempt of reducing the continuous variations of morphological features into a discrete classification (Novotný 1986). As is well-known, the human pelvis, although constituting the

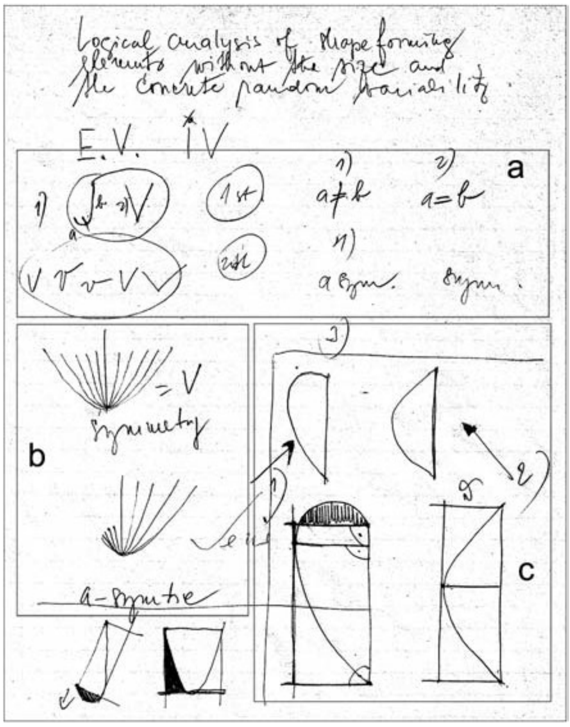

FIGURE 5: Sketch drawn by Vladimir Novotný illustrating the steps of the visual diagnosis of the greater sciatic notch according to the "*ideal shape analysis of form*". The three essential aspects of analysis are highlighted: a) length and proportion of the rami; b) symmetry of the rami; c) course of the posterior ramus.

most sexually differentiated skeletal region, expresses its dimorphism in complex ways due to the evolutionary and functional constraints that determine its general architecture. This is particularly true for the GSN as it is a hinge element between the sacroiliac region and the ischiopubic region, functionally and evolutionarily constrained by the different needs deriving from the emergence of bipedalism and the increase in cranial capacity.

The formalization of the morphological evaluation of the GSN proposed by Novotný in his "ideal shape of form" (*Figure 5*) is of particular interest precisely because the evolutionary, functional and ontogenetic elements that contribute to the expression of the sexually differentiated variability of the GSN, while identified and analysed individually, are however considered in a unitary context.

Nevertheless, Novotný's approach concerns a persistently central question in the field of morphological diagnostics. This problem is essentially referable to the possibility of numerically replicating the diagnosis, expressed in natural language, derived from complex perceptive mechanisms resulting from a high degree of specialization and experience. On the basis of the results of the present work, it appears reasonable to conclude that, if it is not possible to reproduce such complex perceptual mechanisms, it is at least possible to replicate the results in terms of diagnostic efficacy.

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