ANTHROPOLOGIE • XXXII/3 • 1994

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INTER- AND INTRA-OBSERVER ERROR IN PELVIC MEASUREMENTS AND ITS IMPLICATION FOR THE METHODS OF SEX DETERMINATION

ABSTRACT: This article presents an analysis of intra- and inter-observer errors in pelvic measurements commonly used for sex diagnosis, as well as their impact on the results of discriminant function analyses. This allows for an assessment of which variables are the most reliable. Moreover, it is suggested that the indirect technique of measuring of the sciatic notch (shadow image) be replaced by direct measurement (trigonometry). The concordance of sex diagnosis through discriminant functions, that is, the concordance between two observers, two sets of measurements and two techniques, ranges from 88 to 100 %. This variation is due to the proximity, for some bones, of the discriminant function analysis (DFA) result to the discriminant value itself.

KEY WORDS: Os coxae – Measurements – Intra- and inter-observer errors – Sexing.

INTRODUCTION

Measurements are essential to the analysis and interpretation of skeletal remains. These measurements are, however, liable to errors which must be considered, as they are propogated in subsequent statistical analyses and influence interpretations and conclusions. The range of these errors depends on (1) the quality of the skeletal material, (2) the definition of the measurements and the landmark locations, (3) the instrument precision and, finally, (4) human errors during instrument reading and data recording. Few studies in skeletal biology have seriously considered the latter factor.

Both the *precision* and *repeatability* of measurements, that is the error between two successive measurements of the same object by the same observer (intra-observer error), and the *reliability* of the measurements, that is error between two measurements of the same object by two observers (inter-observer error), must be assessed. Conclusions may significantly be modified when error variation is considered. For instance, a biological explanation might be assigned to a significant difference between two samples studied by two different persons, when in fact the variable could have been affected by low reliability. Again, the variation of a parameter between two groups measured by the same observer can reflect either a real difference, or the lack of precision of the measurement technique.

The compressibility of soft parts, leading to differences in measurement, makes consideration of such errors in data collection imperative in anthropometry (Jamison, Zegura 1974), and a number of recent articles bear witness to the importance of this aspect of research (Harrison et al. 1991, Gordon,

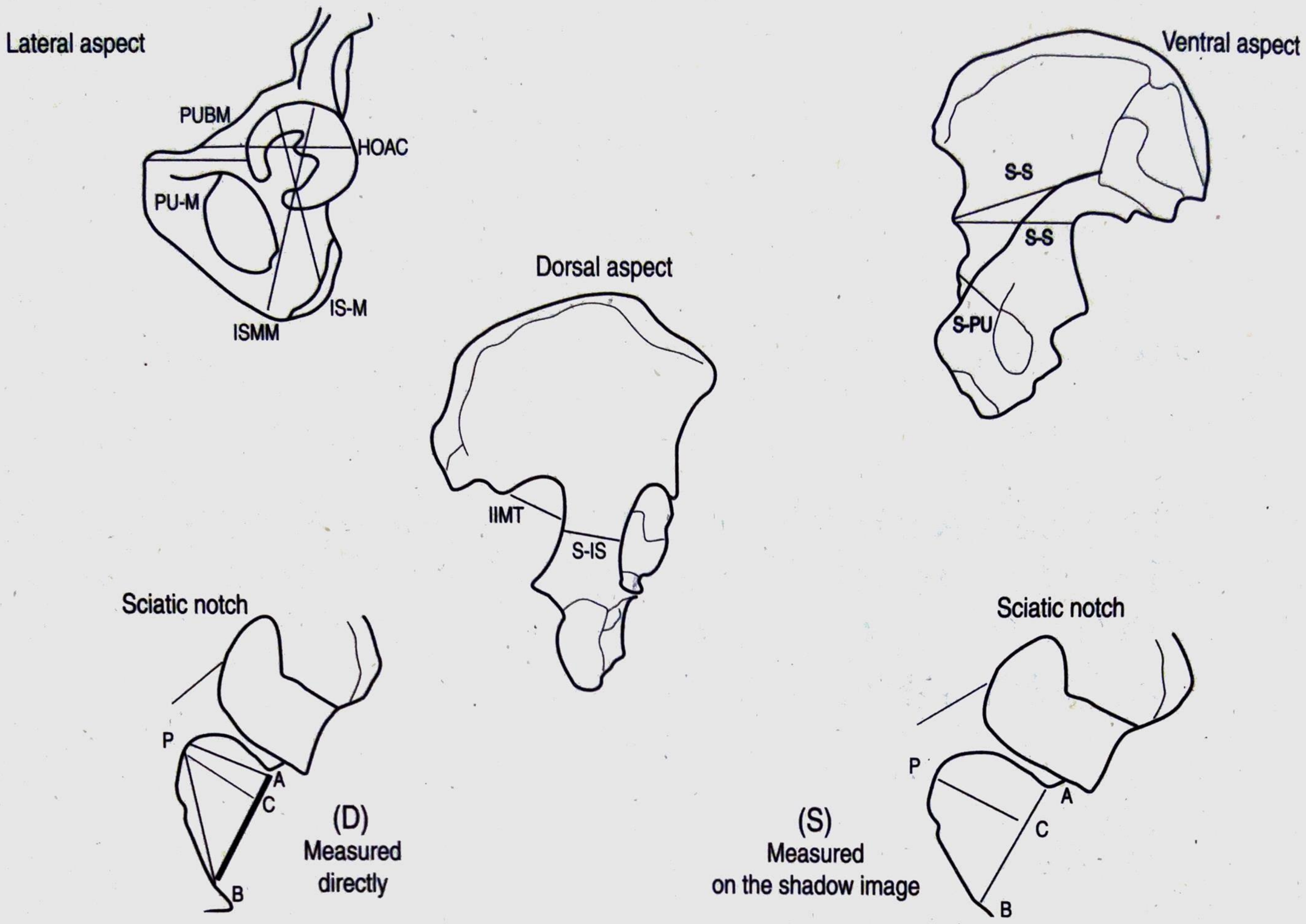

FIGURE 1. *Measurements of the os coxae.*

Bradtmiller 1992, Ishida et al. 1992). By contrast, osteometry has been assumed to be less affected by this kind of problem. However, differences between successive measurements do occur. According to Albrecht (1983), the differential humidity of the bone-stocking area has an impact on linear dimensions and causes a maximum difference of 0.5%. Our knowledge of the scope of intra- and inter-observer errors in osteometry is alarmingly poor even though many studies have confirmed the importance of measurement error (Kouchi, Koizumi 1986, Koizumi, Kouchi 1988, Péres-Péres et al. 1990). Indeed, "these results suggest that investigators employing craniometric measurements to study population affinities, functional morphology, forensics, fossil primates, and human microevolution might profit from conducting a measurement error analysis as an important baseline for the interpretation of the biological significance of their results" (Utermohle, Zegura 1982). Few studies have done so. Holland (1991), working on post-cranial dimensions, selected his variables so as to establish discriminant function analysis (DFA), according to the intra-observer error. Concerning pelvic measurements, only Schulter-Ellis et al. (1988) have considered this problem and noticed that, in a period of two months, the difference between the measurements of the same os coxae by the same person did not exceed two millimetres.

The current research trend in sex determination is that "The early quantitative morphological assessments of sex were gradually replaced by quantitative osteometric approaches" (İşcan 1988). This concerns essentially DFA. According to the statistical theory of DFA, the resulting discriminant function can only be used for the population that provided the sample used to establish it (e.g., Tomassone 1988). This means that a DFA can be used for another population only when it has the same degree of sexual dimorphism as the reference population (Henke 1977) or as a sample of the same population (e.g., Birkby 1966, Holland 1991). Such conditions present a considerable obstacle to using DFA with past populations. The pelvis is the only part of the skeleton that presents a functional sexual dimorphism, as a result of the constraints imposed by locomotion and reproduction. Pelvic DFA, which wholly describes this dimorphism, has been shown to be reliable in other populations (Novotný 1975, 1981, 1983, 1986, Brůžek 1984, 1991, 1992, Schulter-Ellis et al. 1985). We have proposed that sexual dimorphism in the pelvis is stable and similar in human populations because it corresponds to the same functional constraints (Brůžek 1992), and that variations in the value obtained by DFA are due to intra- and inter-observer errors. The importance of measurement error has been previouslydescribed (Jameson, Zegura 1974, Page 1976) and can be a real pitfall when putting DFA into practice.

The aim of the present work is twofold: (1) to determine intra- and inter-observer errors in pelvic measurements used for reliable DFA (Brůžek, 1992) and to estimate their impact on sex diagnosis; and (2) to test the possibility of replacing the classical technique of measurement of the posterior cord of the sciatic notch breadth (AC), by an alternative technique. AC is usually measured by a shadow image technique (Novotný 1975). We suggest direct measurements of the sciatic notch and the subsequent use of trigonometry in order to determine AC. There are several advantages to our proposed method. First, it would be easier to apply DFA during excavation, particularly when bones are brittle and cannot support sampling. Second, it offers a great reduction in materials and cost. We thus investigated the concordance of sex diagnosis between these two methods.

MATERIAL AND METHODS

The study was conducted on a sample of 50 well-preserved os coxae from various medieval archaeological series from the south of France. Sex and age are unknown in this sample. As the purpose of this study consists in comparing the relative results of the sex diagnosis, and thus the repeatability and concordance of DFA, rather than to test their reliability, this is not a serious limitation.

Measurements

Two sets of measurements were made by two researchers (observers A and B), working independently. The two observers are not identically experienced in osteometry. Observer A is a Ph.D. student with 3 years of experience; observer B has 15 years of experience, with special regard to sex diagnosis. Before the study, definitions and techniques of measurement were clarified by both observers. The replicate measurements were taken one week apart.

Among the 18 variables measured (*Fig. 1*) two groups were made: a first group of measurements generally employed in reliable discriminant function analysis (A) and a second group of measurements concerning the greater sciatic notch (B).

A. Pelvic measurements (except sciatic notch)

1. HOAC (M 22) – horizontal acetabular diameter (Bräuer, 1988)
2. IIMT (M 15 (1)) – sciatic notch height (Bräuer, 1988)

TABLE 1. *Mean absolute difference (MAD) of measurements.*

Measurements	MAD (a)		MAD (b)		MAD (a) × MAD (b)		MAD (c)		MAD (d)		MAD (c) × MAD (d)	
	mean	S.D.	mean	S.D.	t	significance	mean	S.D.	mean	S.D.	t	significance
1. HOAC – horizontal acetabular diameter	1.09	0.95	0.90	0.74	1.116	N.S.	1.16	1.08	0.85	0.68	1.718	N.S.
2. IIMT – sciatic notch hight	1.38	1.46	1.24	1.00	0.559	N.S.	1.64	1.48	1.74	1.84	0.299	N.S.
3. ISMM – ischial – post-acetabular ischium length	0.92	0.66	0.93	0.89	0.064	N.S.	1.41	0.88	1.71	1.12	1.489	N.S.
4. ISMM – maximum ischium length	1.82	1.36	1.74	1.36	0.294	N.S.	3.16	2.44	2.27	1.78	2.084	+
5. PUBM – pubic tubercle-acetabular length	0.99	0.88	0.96	0.79	0.179	N.S.	1.43	1.14	1.59	1.08	0.720	N.S.
6. PUM – acetabulo-symphyseal pubic length	0.92	0.87	0.69	0.78	1.392	N.S.	1.21	1.30	1.53	1.89	0.986	N.S.
7. SA – spino-auricular length	0.76	0.71	0.65	0.70	0.780	N.S.	0.88	0.84	0.74	0.66	0.927	N.S.
8. SIS – cotylosciatic breadth	0.38	0.39	0.51	0.77	1.065	N.S.	0.52	0.75	0.61	0.57	0.676	N.S.
9. SPU – cotylopubic breadth	0.42	0.35	0.59	0.70	1.536	N.S.	0.56	0.61	0.55	0.51	0.089	N.S.
10. SS – spino-sciatic length	0.60	0.62	0.48	0.41	1.142	N.S.	0.80	0.78	0.52	0.51	2.125	+
11. SAB – greater sciatic notch breadth*	1.40	1.31	1.52	1.37	0.448	N.S.	2.25	2.23	1.57	2.09	1.573	N.S.
12. SAC – posterior chord of the sciatic notch breadth*	1.78	2.08	1.52	1.65	0.692	N.S.	2.53	3.48	2.26	3.65	0.379	N.S.
13. SAP – distance A – P*	1.57	2.16	1.43	1.47	0.379	N.S.	2.31	3.47	2.05	3.78	0.358	N.S.
14. SBP – distance B – P*	1.59	1.37	1.92	1.62	1.103	N.S.	2.19	1.98	1.58	1.14	1.888	N.S.
15. DAB – greater sciatic notch breadth*	1.41	1.35	1.56	1.35	0.556	N.S.	1.46	1.78	1.77	1.80	0.866	N.S.
16. DAC – posterior chord of the sciatic notch breadth*	1.61	1.83	1.80	1.80	0.523	N.S.	3.05	3.43	2.94	3.29	0.164	N.S.
17. DAP – distance A – P*	1.57	1.91	1.31	1.63	0.732	N.S.	2.30	3.39	2.28	3.20	0.030	N.S.
18. DBP – distance B – P*	1.31	1.31	1.40	1.48	0.372	N.S.	1.98	1.46	1.75	1.39	0.807	N.S.

MAD (a) – intra-observer A; MAD (b) – intra-observer B; MAD (c) – inter-observer, 1st set of observations; MAD (d) – inter-observer, 2nd set of observations

* measured from shadow image; ** directly measured; NS – non significant + – significant (p = 0,05)

3. ISMM – ischial – post-acetabular ischium length (Schulter-Ellis et al. 1983 – IT-A)
4. ISM – maximum ischium length (Thieme, Schull 1957)
5. PUBM – pubic tubercle-acetabular length (Schulter-Ellis et al. 1983 – PS-A)
6. PUM (M 14) – acetabulo-symphyseal pubic length (Bräuer, 1988)
7. SA – spino-auricular length (Gaillard 1960)
8. SIS (M 14 (1)) – cotylosciatic breadth (Bräuer, 1988)
9. SPU – cotylopubic breadth (Gaillard 1960)
10. SS – spino-sciatic length (Gaillard 1960)

B. Sciatic notch measurements

1. *Shadow image*

According to Hanna and Washburn's technique (1953), modified by Novotný (1975), the shape of the sciatic notch is obtained by the exposure of photosensitive paper, on which the os coxae is placed in a posterior position. After several minutes of exposure, the contour is drawn by marking points (A, B, P, C) corresponding to the scheme of the measurements outlined in *Graph 1.*

11. SAB – greater sciatic notch breadth * (Novotný 1975)

TABLE 2. *Technical error of measurement (TEM).*

Measurements	TEM (a)	TEM (b)	TEM (c)	TEM (d)
1. HOAC – horizontal acetabular diameter	1.02	0.82	1.11	0.77
2. IIMT – sciatic notch hight	1.41	1.12	1.56	1.78
3. ISMM – ischial – post-acetabular length	0.80	1.55	1.17	1.44
4. ISMM – maximum ischium length	1.60	0.91	2.81	2.03
5. PUBM – pubic tubercle-acetabular length	0.94	0.88	1.29	1.35
6. PUM – acetabulo-symphyseal pubic length	0.89	0.73	1.25	1.71
7. SA – spino-auricular length	0.73	0.67	0.86	0.70
8. SIS – cotylosciatic breadth	0.38	0.64	0.64	0.59
9. SPU – cotylopubic breadth	0.39	0.64	0.58	0.53
10. SS – spino-sciatic length	0.61	0.44	0.79	0.52
11. SAB – greater sciatic notch breadth*	1.35	1.44	2.23	1.84
12. SAC – posterior chord of the sciatic notch breadth*	1.92	1.58	3.13	3.01
13. SAP – distance A – P*	1.88	1.44	2.93	3.02
14. SBP – distance B – P*	1.48	1.77	2.08	1.37
15. DAB – greater sciatic notch breadth*	1.37	1.45	1.62	1.77
16. DAC – posterior chord of the sciatic notch breadth*	1.72	1.79	3.22	3.10
17. DAP – distance A – P*	1.74	1.47	2.88	2.76
18. DBP – distance B – P*	1.11	1.44	1.73	1.57

TEM (a) – intra-observer A; TEM (b) – intra-observer B; TEM (c) – inter-observer, 1st set of observations; TEM (d) – inter-observer, 2nd set of observations; * measured from shadow image; ** directly measured

TABLE 3. *Regression test obtained on two successive measurements of the AC distance through the relation to the theoretical regression ($y = x$).*

		Comparison of parameters					Classification
		Slopes		Intersection		Decision	Product of probabilities
Observer	Comparison	%	α = 5%	%	α = 5%	α = 5%	
B	1st contra 2nd set, M.S.I.	0.02	+	2.1	+	+	0.05
B	1st contra 2nd set, D.M.	3.4	+	2.4	+	+	8.2
A	1st contra 2nd set, M.S.I.	3.6	+	3.8	+	+	13.5
A	1st contra 2nd set, D.M.	15.4	NS	16	NS	NS	245.3
B	M.S.I. contra D.M., set	4.5	+	64.5	NS	+	290.6
A	M.S.I. contra D.M., set	59.0	NS	33.8	NS	NS	1992.1
B	M.S.I. contra D.M., set	43.7	NS	55.6	NS	NS	2427.9
A	M.S.I. contra D.M., set	83.7	NS	52.1	NS	NS	4365.8

M.S.I. – method of sciatic notch measured from the shadow image; D.M. – method of direct sciatic notch measurements; NS – non-significant difference between parameters; + – identity of parametres is rejected; * – Combination consists in a product of the probabilities in order to classify the tests of reproductibility.

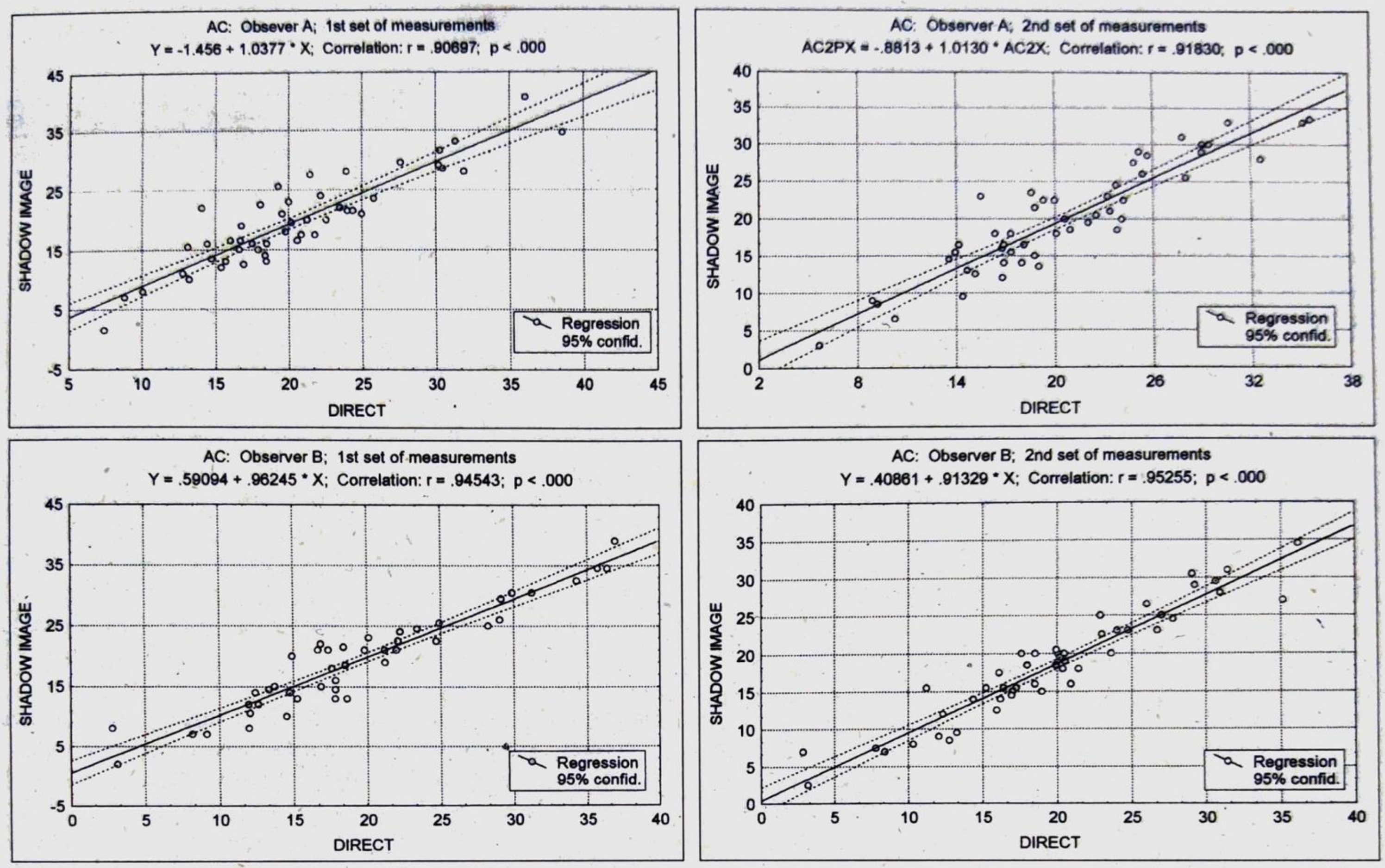

FIGURE 2. *Measurements of the posterior chord of sciatic notch breadth (AC). Regression analysis of shadow image versus direct methods of measurements in two sets of measurements for two observers.*

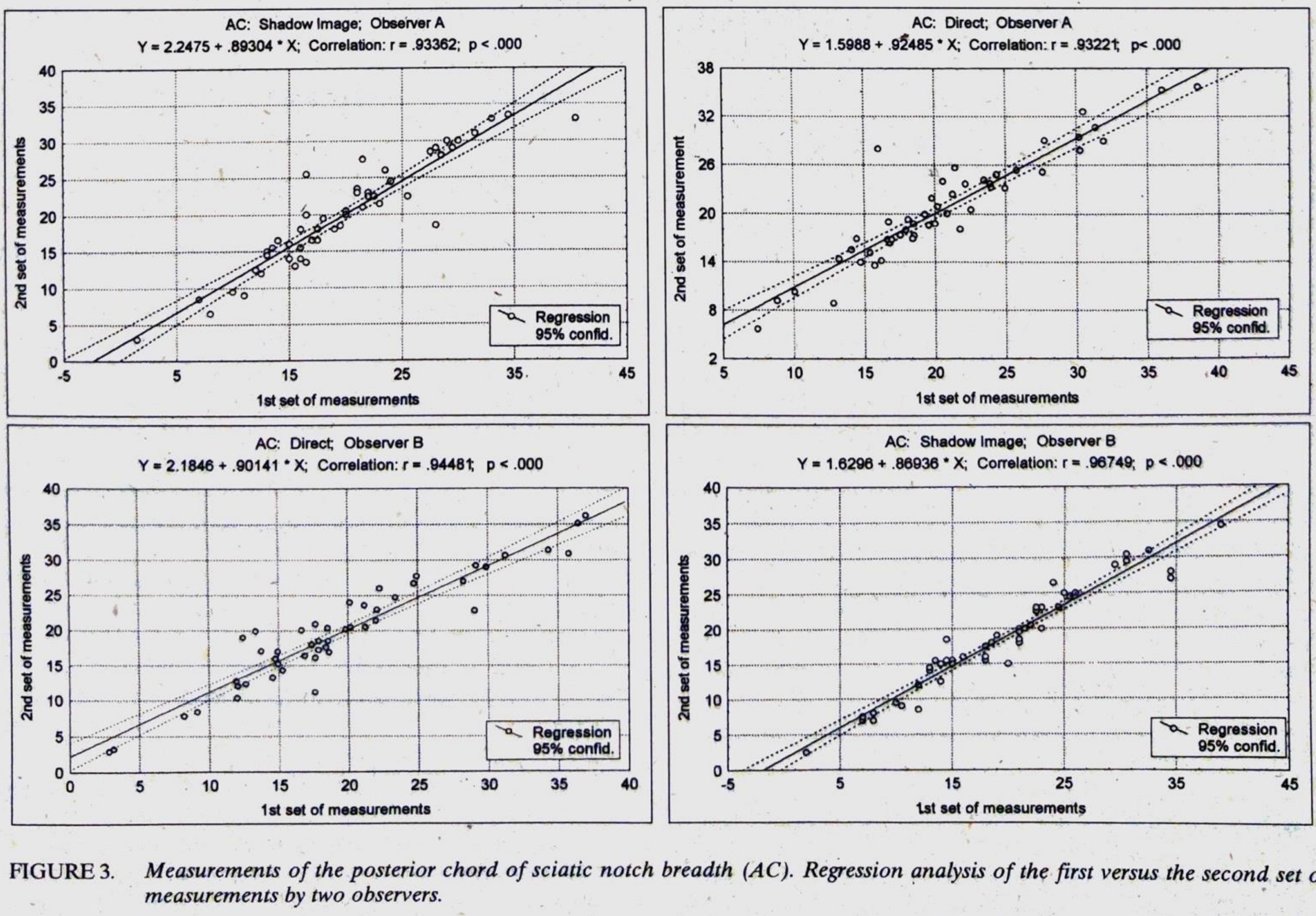

FIGURE 3. *Measurements of the posterior chord of sciatic notch breadth (AC). Regression analysis of the first versus the second set of measurements by two observers.*

TABLE 4. *Intra-observer concordance of sex diagnosis by DFA, according to two posterior chord of the sciatic notch (AC) measurement techniques.*

	Observer A				Observer B			
	1st set contra 2nd set		M.S.I. contra D.M.		1st set contra 2nd set		M.S.I. contra D.M.	
	M.S.I. (%)	D.M. (%)	1st set (%)	2nd set (%)	M.S.I. (%)	D.M. (%)	1st set (%)	2nd set (%)
DFA No 1 (Novotný 1975)	96	92	94	94	94	92	94	100
DFA No 2 (Brůžek 1984)	94	92	98	100	100	100	100	100
DFA No 3 (Brůžek 1992)	96	96	94	94	98	98	100	100
DFA No 4 (Schulter-Ellis et al. 1985)	94	94	100	100	96	96	100	100
Sum of all data	98	96	98	100	100	100	100	100

M.S.I. – method of sciatic notch measured from the shadow image; D.M. – method of direct sciatic notch measurements; n = 50.

12. SAC – posterior chord of the sciatic notch breadth (Novotný 1975)
13. SAP – distance A-P from shadow image
14. SBP – distance B-P from shadow image

* Note: Following Novotný (1975), the breadth of the greater sciatic notch is defined as the distance from the top of the tubercle of the pyramid or, when absent, from the posterior inferior iliac spine (A) to the base of the sciatic spine (B). The landmark position P is the deepest point in the contour of the sciatic notch from the line of the sciatic notch breadth. The landmark position C is the intersection between the perpendicular to DAB passing through P and DAB.

2. *Direct measurements*

We tested the possibility of replacing and simplifying the shadow image technique of sciatic notch measurement by a trigonometric method (proposed by F. Houët) based on direct measurements.

The trigonometric equation used is as follows:

$$DAC = (DAB^2 + DAP^2 - DBP^2) / (2DAB)$$

15. DAB – greater sciatic notch breadth
16. DAC – posterior chord of the sciatic notch breadth
17. DAP – distance A-P directly measured
18. DBP – distance B-P directly measured

Measurements 1 and 3 through 10 were taken with a Helios dial caliper (instrument error 0.1 mm). The other dimensions were measured with a divider (instrument error 0.5 mm). The non-flat bone conformation makes measurement of the greater sciatic notch difficult with a slide caliper.

TABLE 5. *Inter-observer concordance of sex diagnosis by DPA according to two posterior chord of the sciatic notch (AC) measurement techniques.*

	M.S.I. (%)		D.M. (%)	
	1st set (%)	2nd set (%)	1st set (%)	2nd set (%)
DFA No 1 (Novotný 1975)	88	94	88	88
DFA No 2 (Brůžek 1984)	94	92	92	92
DFA No 3 (Brůžek 1992)	94	96	92	90
DFA No 4 (Schulter-Ellis et al. 1985)	94	92	94	92
Sum of all data	96	94	96	92

M.S.I. – method of sciatic notch measured from the shadow image
D.M. – method of direct sciatic notch measurements
n = 50

TABLE 6. *In the extreme case of Tables 4 and 5, the difference is never significant. (nAx, nAy, nBx, nBy are the numbers representing the greatest difference between A and B).*

Fisher's test	nAX	nAy	nBx	nBy	% Ax	% Bx	Prob.	Diff. (0.05)
Intraobserver	50	0	46	4	100.0%	92.0%	0.117	No
Interobserver	48	2	44	6	96.0%	88.0%	0.269	No

Descriptive statistics

1. *Measurement error*

The inter- and intra-observer errors for all variables were recorded as follows:

(A) The mean absolute difference (MAD) was calculated to establish measurer standards because it is known to be poorly correlated with dimensional magnitude (Utermohle et al. 1983; Gordon, Brandtmiller 1992).

$$MAD = \frac{\sum |d|}{n}$$

(MAD = mean absolute difference, d = difference between two measurements; n = size of sample)

(B) The TEM (technical error of measurement, Cameron, 1986) was calculated between the two series of observations (1 and 2) and between observers (A and B). The TEM may be used to monitor measurer performance (e. g., Gordon, Brandtmiller, 1992).

$$TEM = \sqrt{\frac{\sum d^2}{2n}}$$

(TEM = technical error of measurement, d = difference between two measurements; n = size of sample)

In order to investigate the possible extent of measurement errors in the sexing, four DFA were employed:

1. DFA according to Novotný (1975)

y = (ISM × 7,178) – (PUM × 4,789) – (AC × 4,262) – (IIMT × 0,788)

2. DFA according to Brůžek (1984)

y = (HOAC × 0,19420) – (PUM × 0,15688) + (ISM × 0, 10323) – (IIMT × 0,02730) – (AC × 0,05105) – 7,44678

3. DFA according to Brůžek (1991)

y = (ISM × 0,2959) – (PUBM × 0,2162) + (HOAC × 0, 4666) – (AC × 0, 2846) – 37,3070

4. DFA according to Schulter-Ellis et al. (1985)

y = (HOAC/PUM × 25,1462) + (ISMM × 0,1318) – 31,8388

Three evaluations of the concordance of results were assessed: between two observers, between two sets of observations for each person, and between two methods of sciatic notch measurements (for each set of observations and each observer).

We considered sex diagnosis for each isolated DFA and the total sex diagnosis resulting from the sum of the 4 DFA, according to the principle of majority. The percentage of the concordance was tested by Fisher's exact test (hypergeometric law). The regression lines, corresponding to the repeatability and the reproductibility of AC measurements by different techniques, are compared to the first bisectrix as theoretical line (test t of Student of slopes and intersections).

RESULTS AND DISCUSSION

Intra- and inter-observer errors

Table 1 presents means and variations of absolute differences in pelvic measurements (MAD). The intra-observer error ranges from 0.38 to 1.82 for observer A and from 0.48 to 1.92 for observer B. The mean absolute difference is higher for the first group of measurements (No.1 to No. 6) than for the second (No. 7 to No. 10), with values of 1 – 2 mm in the first, compared to values of around 0.5 mm in the second. For the dimensions of the greater sciatic notch, the mean of the intra-observer error ranges from 1.5 to 2 mm. In this case, shadow images and direct methods give the same results. It is interesting to note that the *a priori* instrumental accuracy of sciatic notch measurements is some 5 times lower than those made by using a dial caliper. For the 18 dimensions studied, the variation resulting from intra-observer errors is not statistically significant (t-test).

The mean of absolute differences for inter-observer errors is always of the same order and range, between about 0.5 and 3 mm. The inter-observer MAD for measurements of the greater sciatic notch fluctuates between 1.5 and 3 mm, without differences related to the measurement technique used.

Measurements of the central part of the os coxae (No. 7 to No. 10) show quite identical intra- and interobserver absolute error means, which never exceed 1 mm. Absolute errors are higher for the "maximum ischium length" (ISM) and the "posterior chord of the sciatic notch breadth" (AC). All differences are non-significant, except for the maximum ischium length (ISM) and the spino-sciatic length (SS). It may be recommended that those measurements be replaced by others with non-significantly fluctuating repeatability and reproductibility.

Table 2 presents the technical error of measurement (TEM) of pelvic and sciatic notch measurements. We may note that the experience of the observer in os coxae osteometry does not affect the results. The maximum ischium length (ISM) still displays the highest variation, an observation that supports the replacement of ISM by ISMM.

Measurements of the sciatic notch generally exhibit similar TEM in both methods of measurement. However, inter-obsever TEM for AC is greater than intra-observer error.

Quantitative analysis of the sciatic notch

There is a good correlation between two successive measurements and between the two methods of measurement (*Figs. 2 and 3*). The 8 regression lines were compared to those predicted, and *Table 3* presents the results of the t-test for slopes and intercepts (α = 0.05). Results are arranged in ascending order of the product of probabilities, to show that the reproductibility of results with a change in the technique of measurement is better than the intra-observer repeatability. These results support substitution of the shadow image by the direct method with subsequent trigonometric calculation.

Impact on sexing by means of DFA

Table 4 presents the impact of intra-observer errors on the sex diagnosis with diverse DFA. Observer B, the more experienced, has the maximum concordance for sex determination, taking into account the majority of the results of 4 DFA. The concordance of the second observer ranges from 96 to 100 %. Therefore, the difference of concordance between the two observers is not significant. In the same way, the maximum deviation inside the percentages of concordance (92 and 100 %) is not statistically significant (Alpha = 0.117). All differences of concordance in sexual diagnosis between observers, methods and the DFA employed here are not significant (Fisher's exact test).

It must be noted that the concordance of sex diagnosis between the two methods used is not inferior to that between the two sets of observations using the same methods. Consequently, either method of measurement of the posterior chord of sciatic notch can be used.

The results of the sex diagnosis concordance, between the two observers and according to the technique used, are presented in the *Table 5*. The concordance ranges from 88 to 94 % with Novotny's DFA (1975), and from 90 to 96 % with Brůžek's DFA (1984, 1992). Schulter-Ellis et al.'s DFA (1985), which doesn't use the dimension (AC), gives a concordance ranging from 92 to 94 %. The concordance of the sex determination between the two observers with the 4 DFAs ranges from 92 to 96 %. Fisher's test is not significant thus the technique of measurement of AC doesn't change the results of the DFA. The oscillation of the results depends on other factors than the technique of measurement of the posterior chord of sciatic notch breadth (AC).

We can attribute the observed discordance to the fact that the discriminant value is a very precise number, and that the result of the DFA varies according to the given measurements. Subjects with DFA results close to the discriminant value can be attributed to one sex or another for some small measurement variations. The sex of these "subjects close to the discriminant value" must be considered as indeterminable by these methods. This tells us that, in the future, we will have to consider some new DFA with confidence limits around the discriminant value, inside which the sex will be undetermined.

CONCLUSIONS

We have investigated how the magnitude of measurement error and the measurements selected for sexual determination may be of interest in performing DFA research. In our study, the observer's experience does not significantly effect intra-observer error in the reliability of coxal measurements, if the observers have been trained to take osteometric measurements. Our analysis of intra- and inter-observer errors shows differences of repeatability according to measured dimensions, and emphasizes that the subsequent choice of variables for the establishment of metric criteria for the sex diagnosis must take the reliability of the measurements into account.

We have shown that direct measurements of the sciatic notch can replace measurements obtained by shadow imaging. The "AC" distances obtained by both methods are tatistically identical and, for every dimension of the sciatic notch, intra- and inter-observer errors are very similar in both methods. Finally, the concordance of sex diagnosis is very good, and depends neither on the observer nor on the use of different methods for measurement of the sciatic notch. We observe a fluctuation of the results for the coxals close to the discriminant value DFA results, and suggest the importance of future work that considers confidence limits in these analyses.

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