Consideration of Accuracy and Observational Error Analysis in Pelvic Sex Assessment: A Study in a Thai Cadaveric Human Population

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ABSTRACT

Objective: In situations where skeletal human remains are recovered, pelvic bone morphology has been demonstrated to have an essential role in forensic sex identification. Determination of sex is one of the four pillars used to construct a biological profile of unidentified skeletal remains. Such analysis has mainly been confined to direct visual inspection or morphometric analysis of pelvic elements available. This study evaluates the identification accuracy and classification error established based on a morphometric sex determination of this bone either by direct observation or digital image analysis.

Materials and Methods: We used morphometric analysis of human pelvic bone from modern Thai samples to clarify the effect of variation in pelvic morphometric parameters on prediction accuracy. A total number of 408 pelvic bones (Male, n=249 and Female, n=159) were examined. Pelvic morphometric variables were measured in multiple regions for each bone.

Results: We found statistically significant differences in the pelvic morphometric parameters measured between the two sexes with considerably accurate classification and unavoidable errors by all means of analytical assessment.

Conclusion: Our findings suggest that it is not only variation of pelvic morphometric parameters between the two sexes in this population, but also the selection of analytical approach that can impact prediction accuracy and thus may contribute to the effect on the determination of sex. Ethical approval was not required for this study.

Keywords: Morphometric analysis; forensic anthropology; sex estimation; technical error of measurement (Siriraj Med J 2022; 74: 330-339)

INTRODUCTION

Forensic examiners must establish a biological profile when identifying unknown human remains, including sex, age, stature, and ancestry. This information can be compared with antemortem records and other information contributing to the identification process. Analysis of skeletal remains should be organized promptly to assess sex. Skeletal sex estimation is crucial for forensic anthropologists and forensic osteologists in developing a biological profile since sex assessment serves as a foundation for developing other aspects of a biological profile.[1-4] As part of a significant step to establishing a biological profile and personal identification, this process requires experience and needs accurate decision-making.

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The manifestations of sex characteristics within bones are different in both sexes under genetic influence and hormonal regulations.[5] They make up their skeletal components and these distinctive skeletal traits can be used to differentiate males from females.[6,7] A reliable and less subjective technique for assessing sex should be conducted and documented to emphasise the identification performed.

Accurate and valid assessments of sex are used in field and laboratory settings for determining sex from skeletal remains.[8] Many studies have focused on gross skeletal features, utilizing cranial or postcranial bones.[9-11] In general, the selection of pelvic bone from unidentified human remains is preferable to estimate sex because of a high level of certainty and validity due to the sexual dimorphism demonstrated within this bone.[12,13] Studies have examined the utility of human pelvic bone to estimate sex, and in many cases, these lack intra- and inter-observer comparisons of observational error.[14,15] The estimation of sex can be established by visual assessment based on observing sexual dimorphic differences.[10] This method to estimate sex from the os pubis evaluates the different degrees of morphological traits to differentiate between the two sexes. It can be performed by using various morphologic characteristics, such as the subpubic concavity and the medial aspect of the ischio-pubic ramus.[16]

Alternatively, several morphological features of the pelvic complex can indicate the biological sex of individuals, including the size and shape of the os pubis, greater sciatic notch, obturator foramen, the existence or absence of the preauricular sulcus and evidence of parturition scars. However, sex estimation utilizing gross pelvic morphology requires complete or nearly complete skeletal elements. When the pelvic complex is less damaged, this method is achievable. However, morphological assessment becomes more challenging when these bones appear fragmented or severely damaged by taphonomic factors. For these reasons, an alternative method for sex estimation utilizing digital images of the specific characteristics from pelvic bone should be considered.[17]

Despite the acceptable accuracy, an estimation of sex utilizing gross morphology has several limitations. This method creates both intra- and inter-observer errors causing variation between observers and is non-reproducible. The decision-based observational method is highly subjective. It can be especially problematic when it appears to be undetermined or unclassified. Accordingly, sex estimation using pelvic morphometrics by direct measurements has been introduced to increase the certainty and accuracy.[18]

This method of sex estimation from the pelvis is problematic because it is regionally dependent.[19,20] Complete pelvic elements are required when determining the sex of unknown skeletal remains using either the non-metric method or metric analysis. This means that the degree of certainty in establishing sex from severely damaged pelves due to taphonomic causes is reduced. Consideration of an alternative pelvic landmark to establish sex identification is essential, especially when encountering fragmented pelvic bones. A morphologic analysis is mainly focused on the pubic region. Such analysis relies on either the presence or absence of morphological traits or the degree of expression.[21] When comparing anterior and posterior regions of the pelvic bone, it is clear that the pubis, being located anteriorly, has a high possibility of being exposed to postmortem changes. As a result, it can be impossible to establish sex. In terms of pelvic anthropometric sex assessment, this method relies on measuring observational characteristics. It utilizes individual measurements or combinations of measurements to differentiate the two sexes. The accuracy rate of prediction depends on the selection of skeletal landmarks utilized in this analytical method. The posterior region of the pelvic bone is more robust than the anterior border, and measurements of skeletal landmarks from this area are achievable.[22]

Metric sex estimation using the pelvic bone is more precise than visual morphological analyses and can exceed an accuracy rate of 90%. However, this approach requires a complete or nearly complete pelvic complex to assess all the landmarks proposed by current literature. The ischio-pubic index provided the most accurate sex estimation of 96.5%.[23] Supportive results of the ischio-pubic index as a sex indicator from pubic measurements were analyzed and achieved 90% accuracy.[24]

It is necessary to consider that either the non-metric or metric analytical methods using pelvic elements depend upon identifiable morphologic features, which in turn depend upon the bones being intact or nearly intact. Currently, sex estimation methods are mainly established from the pelvis samples from specific (black and white American) skeletal collections, whereas morphological traits for Asian and other ethnic groups are limited.[25,26] Several authors suggested that population-specific databases and classification analysis for sex estimation in heterogeneous populations are crucially required.[27]

This research will focus on the prediction accuracy and intra- and inter-observer observational errors from three different sex estimation methods, including estimating sex from gross morphological sex characteristics, digital images, and a measured analytical approach in a modern Thai population utilizing human pelvic dry bones.

MATERIALS AND METHODS

The study was conducted on 408 human pelvic bone samples from the Siriraj Bone collection, Department of Anatomy, Faculty of Medicine Siriraj hospital, Mahidol University. For each bone, three gross morphologies based on the Phenice method, including the presence of ventral arc, inferior pubic ramus and subpubic concavity, were used to determine sex. Subsequently, three digital images were taken from each bone to determine an inter-observer accuracy and error of sex assessment using the Phenice criteria. Pelvic morphometric parameters (Fig 1) were measured from each bone. The usefulness of iliac associated bony landmarks for assessing sex was examined. This was done by analysing sex discriminant functions for sex indicators of those measurements taken from prominent posterior foci to the anterior iliac bony landmarks. The parameters measured in this method are located on the anterior and posterior border of the ilium, including ASIS, AIIS, PSIS, and PIIS. Additional parameters were measured from those two iliac borders to other skeletal landmarks: the pubic tubercle and ischial spine. Pelvic landmarks and morphometric measurements were described as shown in Table 1. The mean and standard deviations were calculated for each parameter. Statistical analyses using paired student's t-tests were performed to evaluate the differences between each group. The null hypothesis was rejected where the difference between groups was 0. A p-value of <0.05 was interpreted as being statistically significant. Inferential statistics were used to determine discriminant function analysis (total analytical sample) and evaluate the probability of sex prediction and classification accuracy for those variables that revealed statistically significant differences. The best discriminant functions were compared and selected based on positive prediction accuracy.

Observational error and reliability analysis

Intra-observer error of measurement evaluation (Table 3).

Two measures were used in this observational study to investigate intra-observer measurement error rates between two separate measurements taken by the same investigator. The measurements were taken by the researcher who did this study, who first measured morphometric characteristics from pooled human pelvic samples, then took a second measurement. The interval between the first and second measurements was two weeks. To quantify intra-observer error, researchers measured pelvic bone-related data. Six variables were measured: PL, IL, vertical and horizontal Acetabular diameters, and obturator foramen diameters. The statistical difference between the two measurements was analysed using the student t-test.

Inter-observer error of measurement evaluation (Table 3).

Two observers conducted two sets of measurements independently to investigate an inter-observer technical error of measurement between two independent investigators. The researcher who conducted this current investigation and analysed bone samples was the first witness. Each of the six parameters was assessed. The second observer was a ten-year anatomical academic staff member who evaluated the pelvic parameters using the same pelvic samples. The objective of this study was to quantify the inter-observer measurement error and the repeatability. The instructions and descriptions for data collection were supplied to the second observer. Before conducting the inter-observer inquiry, the observers were given definitions for six criteria. A brief session was provided to measure the variables with the anthropometric tools. For non-bias considerations,

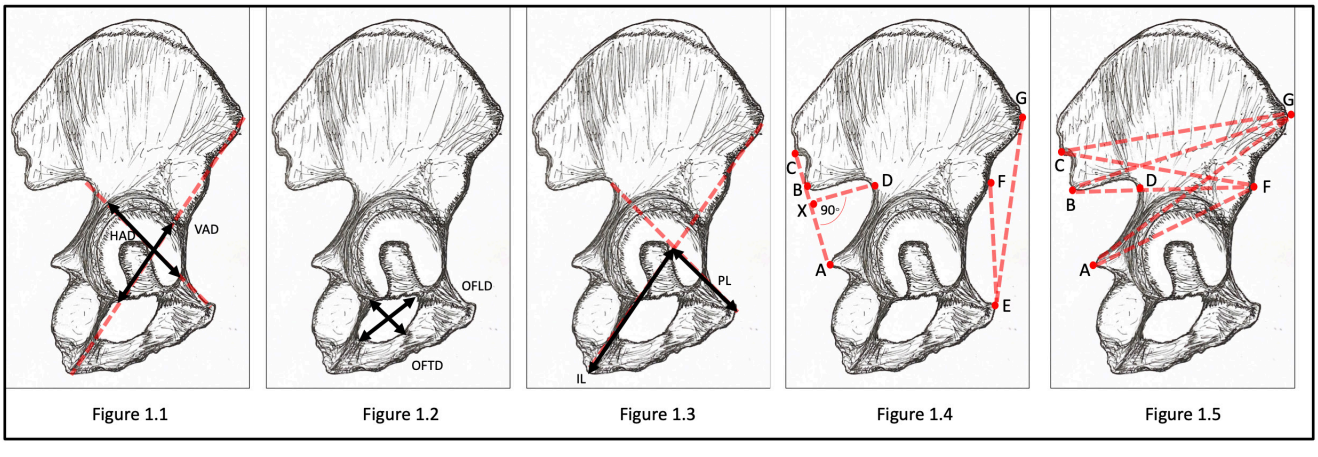

Fig 1. Diagrams illustrating pelvic morphometric landmarks and dimensional measurements.

TABLE 1. Description of pelvic landmarks and morphometric measurements.

	Pelvic morphometric landmarks and descriptions
VAD	Vertical Acetabular Diameter
HAD	Horizontal Acetabular Diameter
MAD	Mean Acetabular diameter
OFLD	Obturator Foramen Longitudinal Diameter
OFTD	Obturator Foramen Transverse Diameter
MOFD	Mean Obturator Foramen diameter
OF index	Obturator Foramen index
PL	Pubic Length
IL	Ischial Length
P/I index	Pubic/Ischial length index
A	Ischial spine
B	Posterior inferior iliac spine (PIIS)
C	Posterior superior iliac spine (PSIS)
D	Highest point of greater sciatic notch
E	Pubic tubercle
F	Anterior inferior iliac spine (AIIS)
G	Anterior superior iliac spine (ASIS)
AB	Distance between ischial spine and PIIS
BC	Distance between PSIS and PIIS
XD	Maximal greater sciatic notch heigth
EF	Distance between pubic tubercle and AIIS
EG	Distance between pubic tubercle and ASIS
BG	Distance between PIIS and ASIS
CG	Distance between PSIS and ASIS
AG	Distance between ischial spine and ASIS
BF	Distance between PIIS and AIIS
AF	Distance between ischial spine and AIIS
CF	Distance between PSIS and AIIS

the measurement was carried out without knowing the sample's demographic characteristics. The statistical difference between the two observers was investigated using a paired student t-test. The intra-observer error rates for two measures and the inter-observer error rates for two observers were calculated for the conventional morphometric measurement. Repeatability between observations/observers was assessed, calculating the technical error of measurement (TEM), relative technical error of measurement (rTEM) and coefficient of reliability (R). These values indicate the repeatability between two observations.[28] TEM is calculated as follows,

$$TEM=\sqrt{(\Sigma D^2)/2N}$$

(D = difference between the two observers or measurements 1 and 2, and N = the total number of tested samples. Subsequently, the relative TEM (rTEM) was calculated using the formula as shown below:

$$rTEM= (TEM/ mean) \times 100$$

An agreement threshold between observations is accepted at a 5% cut off value.[29] This study assesses the coefficient of reliability (R) to determine a repeatability in anthropometric measurement.[30] It was calculated using the formula as shown below:

$$R= 1 - ((TatalTEM)2/SD^2)$$

The value of coefficient of reliability (R) ranges from 0 to 1. Levels of reliability coefficient (R) are accepted when the values were > 0.95.[27]

The relationship between pelvic morphometric variables and known sex were examined using discriminant function analysis. The entire dataset was utilised at this stage of the analysis (N = 408). Ten discriminant functions were created (Table 4) shows a summary of all functions and parameters.

RESULTS

Descriptive statistics for the pelvic measurements are summarized in Table 2, including group means, standard deviations, variances and minimum and maximum values. Means of all pelvic measurements were significantly different between males and females ($p < 0.05$), except for obturator foramen transverse diameter (OFTD).

Table 3 shows the summary of descriptive statistics and intra- and inter-observer technical error of measurement values and the reliability coefficient obtained from all six measurements. Among the six variables, the results

TABLE 2. Descriptive statistics of pelvic landmarks and morphometric variables (* represented no statistical difference).

Variables	Male (n=249)					Female (n=159)					*P-value*
	Mean	*Std Dev*	*Variance*	*Minimum*	*Maximum*	*Mean*	*Std Dev*	*Variance*	*Minimum*	*Maximum*	
VAD	49.05	2.88	8.28	40.36	57.28	44.14	2.74	7.52	34.14	51.98	< 0.05
HAD	49.99	2.85	8.10	39.88	59.79	45.11	2.97	8.81	36.33	64.84	< 0.05
MAD	49.52	2.72	7.39	40.12	58.54	44.62	2.67	7.10	35.24	55.73	< 0.05
OFLD	50.61	3.69	13.64	39.08	63.63	46.62	3.51	12.30	38.57	58.74	< 0.05
OFTD	32.96	3.44	11.85	21.70	44.66	33.32	3.36	11.29	21.69	43.27	0.29*
MOFD	41.78	3.19	10.19	30.64	54.15	39.97	3.06	9.35	31.80	47.75	< 0.05
OF index	65.17	5.54	30.72	47.63	80.84	71.54	5.93	35.17	51.75	87.92	< 0.05
PL	70.44	5.69	32.39	54.88	86.55	68.10	5.52	30.44	55.92	81.69	< 0.05
IL	87.96	6.03	36.31	64.21	119.40	79.63	5.04	25.36	67.58	91.52	< 0.05
P/I index	80.23	6.00	36.04	67.18	99.94	85.67	6.74	45.48	69.54	105.49	< 0.05
AB	54.52	5.70	32.53	37.42	70.01	60.97	7.10	50.44	43.08	84.43	< 0.05
BC	36.79	5.35	28.67	21.30	51.11	32.64	4.71	22.21	18.24	45.41	< 0.05
AB+BC	91.31	7.68	58.97	72.78	112.68	93.61	8.79	77.20	70.23	129.18	< 0.05
XD	35.84	3.20	10.27	27.69	44.51	33.70	3.70	13.68	24.96	45.77	< 0.05
EF	85.77	6.07	36.90	61.24	105.79	83.40	6.31	39.83	69.66	99.79	< 0.05
EG	119.34	9.69	93.86	78.01	149.48	116.75	8.60	73.88	96.53	146.62	< 0.05
BG	13.20	0.75	0.56	10.60	15.50	12.65	0.85	0.72	10.20	14.90	< 0.05
CG	14.61	0.83	0.69	11.00	16.80	14.22	0.86	0.74	12.00	16.50	< 0.05
AG	13.16	0.74	0.54	11.00	15.50	12.30	0.70	0.49	10.50	14.50	< 0.05
BF	11.25	0.72	0.52	8.50	13.60	10.79	0.80	0.64	8.70	12.90	< 0.05
AF	10.11	0.69	0.48	7.80	13.50	9.20	0.62	0.39	7.50	11.00	< 0.05
CF	13.36	0.76	0.58	10.00	15.70	12.84	0.81	0.66	10.20	14.80	< 0.05

TABLE 3. Comparisons of intra- and inter-observer technical errors of measurement (TEM) and Reliability coefficient (SD – standard deviation, Ab TEM – Absolute TEM, rTEM – relative TEM, R – Reliability coefficient).

	Intra-observer error								Inter-observer error							
	Mean		SD		p value	Ab TEM	rTEM	R	Mean		SD		p value	Ab TEM	rTEM	R
	Measurement1	Measurement2	Measurement1	Measurement2					Observer1	Observer2	Observer1	Observer2				
VAD	47.137	47.301	3.704	3.596	0.112	1.473	3.120	0.837	47.137	47.288	3.704	3.490	0.200	1.68	3.558	0.782
HAD	48.090	48.191	3.748	3.701	0.044	0.71	1.475	0.964	48.090	48.185	3.748	3.201	0.392	1.57	3.261	0.797
OFLD	49.056	49.202	4.109	4.115	0.105	1.29	2.626	0.901	49.056	49.257	4.109	4.192	0.126	1.86	3.784	0.799
OFTD	33.096	33.179	3.411	3.385	0.282	1.39	3.289	0.832	33.096	33.167	3.411	3.260	0.569	1.78	5.372	0.715
PL	69.524	69.316	5.732	5.608	0.032	1.38	1.988	0.941	69.524	68.893	5.732	5.258	0.000	2.55	3.685	0.786
IL	84.714	84.708	6.963	6.766	0.961	1.66	1.960	0.941	84.714	84.647	6.963	6.554	0.649	2.11	2.492	0.903

TABLE 4. Comparisons of Canonical discriminant function coefficients for pelvic dimensions, discriminant classification function and classification matrix.

Canonical discriminant function coefficients for pelvic dimensions

Functions and parameters		Raw Canonical Coefficients	Standardized Canonical Coefficients (Pooled Within-Class)	Total Canonical Structure	Group Centroids		Discriminant Classification Function								Classification Matrix				
Function1	OFLD	0.343	1.242	0.819	F	-0.887	Group	OFLD	OFTD	Constant					Group \ Predicted	F	M	Total	Percent Correct
	OFTD	-0.238	-0.812	-0.089	M	0.566	F	3.018	0.956	-86.266					F	90	69	159	56.604%
	Constant	-8.933					M	3.516	0.61	-99.016					M	37	212	249	85.141%
															Total	127	281	408	74.02%
															Number of correct = 302				
Function2	MAD	0.393	1.062	0.994	F	-1.12	Group	MAD	MOFD	Constant					F	126	33	159	79.245%
	MOFD	-0.051	-0.161	0.407	M	0.715	F	5.024	2.117	-154.411					M	26	223	249	89.558%
	Constant	-16.63					M	5.746	2.023	-184.549					Total	152	256	408	85.539%
															Number of correct = 349				
Function3	PL	0.149	0.836	0.335	F	-0.926	Group	PL	IL	PII	Constant				F	115	44	159	72.327%
	IL	0.034	0.19	0.98	M	0.591	F	-248.775	207.126	210.282	-8,783.987				M	32	217	249	87.149%
	PII	-0.164	-1.031	-0.652			M	-248.549	207.177	210.034	-8,783.306				Total	147	261	408	81.373%
	Constant	0.282													*Number of correct = 332*				
Function4	VAD	110.349	311.844	0.97	F	-1.109	Group	VAD	HAD	MAD	Constant				F	124	35	159	77.987%
	HAD	110.33	319.357	0.964	M	0.708	F	3.719	3.594	-1.188	-136.813				M	27	222	249	89.157%
	MAD	-220.308	-594.476	1.			M	4.242	4.016	-1.453	-168.813				Total	151	257	408	84.804%
	Constant	-17.645													*Number of correct = 346*				
Function5	AB	0.118	0.741	0.77	F	0.894	Group	AB	BC	XD	Constant				F	103	56	159	64.78%
	BC	-0.102	-0.522	-0.633	M	-0.571	F	1.423	1.098	2.554	-104.329				M	37	212	249	85.141%
	XD	-0.132	-0.448	-0.504			M	1.25	1.248	2.746	-106.251				Total	140	268	408	77.206%
	Constant	1.475													*Number of correct = 315*				
Function6	BG	0.331	0.26	0.61	F	-0.768	Group	BG	CG	AG	Constant				F	62	96	158	39.241%
	CG	-0.662	-0.557	0.413	M	0.488	F	4.569	9.442	13.432	-178.746				M	38	211	249	84.739%
	AG	1.559	1.125	0.955			M	4.985	8.61	15.39	-197.064				Total	100	307	407	67.076%
	Constant	-14.726													*Number of correct = 273*				
Function7	AF	1.82	1.211	0.976	F	-0.865	Group	AF	BF	CF	Constant				F	108	51	159	67.925%
	BF	-0.325	-0.244	0.502	M	0.552	F	6.594	4.758	14.186	-147.09				M	39	210	249	84.337%
	CF	-0.178	-0.139	0.54			M	9.174	4.297	13.933	-163.599				Total	147	261	408	77.941%
	Constant	-11.803													*Number of correct = 318*				
Function8	MAD	-0.297	-0.8	-0.911	F	1.327	Group	MAD	MOFD	OFI	PII	Constant			F	136	23	159	85.535%
	MOFD	-0.008	-0.024	-0.373	M	-0.847	F	5.824	1.166	1.574	1.958	-293.442			M	20	229	249	91.968%
	OFI	0.077	0.437	0.659			M	6.469	1.182	1.408	1.87	-305.777			Total	156	252	408	89.461%
	PII	0.04	0.255	0.534											*Number of correct = 365*				
	Constant	5.913																	
Function9	AB	-0.138	-0.87	-0.769	F	-0.895	Group	AB	BC	EF	EG	Constant			F	109	50	159	68.553%
	BC	0.092	0.47	0.633	M	0.572	F	0.922	0.841	1.387	0.359	-120.523			M	32	217	249	87.149%
	EF	0.064	0.393	0.317			M	0.719	0.975	1.48	0.378	-123.615			Total	141	267	408	79.902%
	EG	0.013	0.138	0.257											*Number of correct = 326*				
	Constant	-2.27																	
Function10	VAD	0.161	0.456	0.889	F	-1.328	Group	VAD	HAD	OFLD	OFTD	PL	IL	Constant	F	136	23	159	85.535%
	HAD	0.12	0.347	0.873	M	0.848	F	1.524	2.012	1.317	0.481	0.737	0.606	-166.936	M	19	230	249	92.369%
	OFLD	0.105	0.381	0.651			M	1.875	2.273	1.546	0.148	0.64	0.717	-198.467	Total	155	253	408	89.706%
	OFTD	-0.153	-0.522	-0.071											*Number of correct = 366*				
	PL	-0.044	-0.25	0.274															
	IL	0.051	0.29	0.801															
	Constant	-14.728																	

demonstrated statistically significant differences in HAD and PL between the two measurements (p-value of < 0.05). HAD demonstrated intra-observer error rates with R value > 0.95. This finding indicates high repeatability with only the HAD not exceeding the 5% acceptance threshold. In terms of inter-observer error analysis, statistical analysis demonstrated that only PL examined by the two observers was statistically significantly different (p-value of < 0.05). The six pelvic parameters demonstrated inter-observer error rates with R value < 0.95. These findings indicate low repeatability with all measured variables not exceeding the 5% acceptance threshold.

When accuracy for estimating sex by direct observation using Phenice's characteristic was compared with sex assessment using Phenice's pelvic morphologies digital images, 91.42% accuracy was achieved from sex estimation based on gross pelvic examination (373/408). Similar figures were obtained from two observers (90.32%, 84/93 and 87.09%, 81/93) using pelvic morphologies digital images approach based on Phenice's characteristics with the mean accuracy of 88.71%.

Table 4 shows the standard, structure and unstandardized coefficients, the group centroids, results, and the discriminant function analysis results from the study data. For all of the ten discriminant functions produced for sex determination, sex was correctly assessed with an accuracy between 67.07% and 89.46%. Using the discriminant function analysis of pelvic dimensions, the lowest accuracy in the prediction was observed from Function 6 when using a combination of BG, CG and AG as a sex predictor with an accuracy of 67.07%. The best discriminator between the sexes with the highest predicted accuracy was achieved using VAD, HAD, OFLD, OFTD, PL and IL with an accuracy of 89.71%.

For the function using only acetabular-related variables, average accuracy was 84.8%; using only obturator foramen-related variables classification accuracy was 74.02%. Function 5, where sciatic notch measurements were assessed, performed an average accuracy of 81.37%. Functions established from distances measuring ASIS and AIIS to the posterior pelvic landmark achieved an accuracy of 67.08% and 77.94%, respectively.

DISCUSSION

Skeletal sex estimation can be assessed by visual observation of morphological variation in the bones because of sexual dimorphism.[32] Skeletal size and robusticity, attributed by extrinsic factors such as biomechanics, interact with bones, and intrinsic factors including genetic and sex hormones, are the preferable sex indicator. Cranial and postcranial skeletal elements exhibit sexual dimorphism observed in adult skeletons.[8] Non-metric analysis of pelvic morphology, along with metric methods, is the most reliable sex indicator for adult skeletons.[8] Within the pelvis, the morphology of the pubic region is thought to establish the most reliable indicators for sex estimation. Existence of the ventral arc, the subpubic

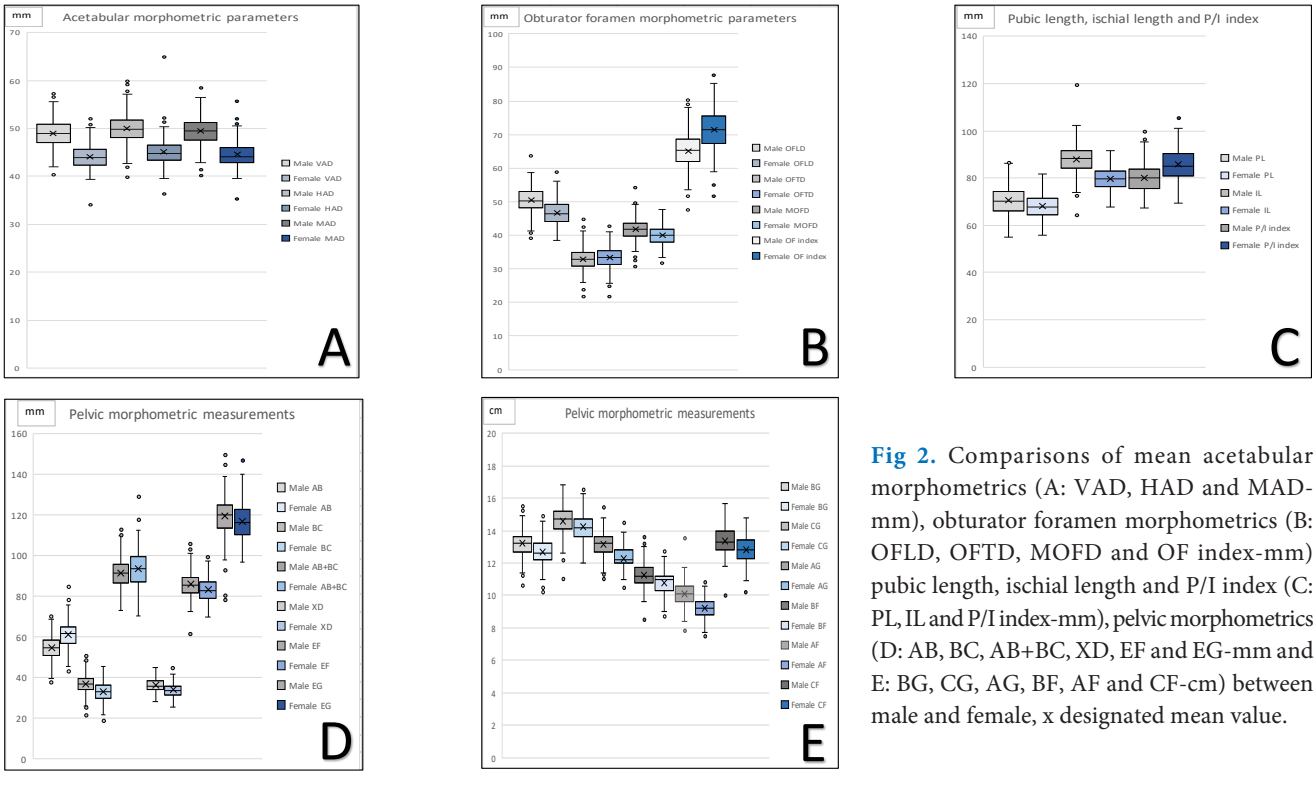

Fig 2. Comparisons of mean acetabular morphometrics (A: VAD, HAD and MAD-mm), obturator foramen morphometrics (B: OFLD, OFTD, MOFD and OF index-mm) pubic length, ischial length and P/I index (C: PL, IL and P/I index-mm), pelvic morphometrics (D: AB, BC, AB+BC, XD, EF and EG-mm and E: BG, CG, AG, BF, AF and CF-cm) between male and female, x designated mean value.

concavity, and the morphology of the medial surface of the ischiopubic ramus was introduced by Phenice as an accurate method for sex estimation. Phenice's pelvic morphological traits have been further validated with improved accurate prediction and reduced classification errors.[15,24,33,34]

The morphologies of the acetabulum, the size of the obturator foramen, and the pubic and ischial lengths can reveal sex differences. In addition, studies report other morphological features that are possible for sex indicators within the pelvic bone, including the acetabulum and the greater sciatic notch.[35] These anatomical regions have a durability that potentially endures destructive processes more readily than the pubis. The use of morphometric measurement incorporated with stepwise-selected discriminant functions can yield more accurate classification than observational morphometric approaches. Nonetheless, analysis using a digital image is achievable. This study found that this method can provide less accuracy than direct observational sex differentiation.

While most adult skeletons demonstrate sexually dimorphic characteristics, the validity of sex assessment is also influenced by other factors: population variations, age, and pathological and taphonomic changes. The expression of sexual dimorphism is variable among and across populations. Therefore, it is necessary to consider comparative data from a specific population when applying these techniques in forensic circumstances.[36] Sexual dimorphism and the differences between the sexes vary in other populations. In addition, different methodologies, including morphological and metric features, may analyze skeletal remains for sex estimation. Skeletal differences in morphological attributes vary by shape, morphological traits, and relative size between the sexes. Methods based on the shape and size of the pelvis and the presence or absence of pelvic characteristics are favoured. Other morphological features may represent sex differences. However, they are usually less accurate than methods using distinct morphological features with substantial sexual dimorphism and observations. Instruments, standards, appropriate analytical software and a combination of measurements and multivariate approaches can increase reliability in sex evaluations, although a single measurement may provide reasonably reliable sex estimation.

It is well acknowledged that intra- and inter-observer error caused by visual or metric variables can lead to disparities in sexual dimorphism evaluation and sex determination. Current studies, however, have shown that visual assessment is associated with significant levels of inter-observer error due to imprecise variable definitions, substantial reliance on previous observer experience, and the seriation process employed to sort the individuals. This error measurement analysis reveals that geometric morphometrics produces good intra- and inter-observer agreement.

Pelvic morphologies can be differentiated consistently even among observers with no prior experience. However, those with obscure morphologies are exceedingly difficult to determine consistently. Our findings show that even observers familiar with pelvic analysis using sexual dimorphism have an inconsistent interpretation of coordinative landmarks for assessing sex; even though the presence of the ventral arc is the best sex indicator for females, determination of sex from digital images still establishes various degrees of prediction accuracy among observers. This shows that descriptive anatomical landmarks may be misinterpreted in the ischiopubic regions.[24,35] It is worth describing the quantitative methodologies utilizing the pelvic characteristics which show sexual dimorphism variance. These methodologies are relevant and applicable to every forensic practitioner. The effect of sex estimation utilizing pubic length, ischial length and P/I index on classification accuracy is critical. The description of anatomical landmarks for these measurements, especially the pubic length, is diverse among current literature. In this study, measurement of pubis length and ischial length between the two observers revealed lower reliability than results from an intra-observer error of measurement, indicating a low reproducibility.

Additionally, the definition of a specific landmark being measured within the acetabulum is identical to a problematic issue occurring in the ischiopubic region.[37,38] All measurements should be repeatable and independent. Therefore, future research should incorporate an assessment of the interobserver error in these dimensions to avoid sex misinterpretation.

The integration of the iliac landmark measurement and the assessment of pubic sex characteristics should be considered when dealing with skeletal parts and severely fragmented skeletal remains to improve sex prediction accuracy. The range of prediction accuracy from discriminant functions utilizing these measurements in this study was 67.08% (Function6)-79.9% (Function9), indicating that those measurements are potentially reliable in estimating the sex, as highlighted in previous studies.[22,39,40] Thus, sex discrimination utilizing iliac measurement can be conducted independently.[41] However, a correct estimation between an isolated morphometric measurement analysis and the morphological assessment showed that the former established a less favourable outcome and provided a lower prediction accuracy than the latter

method. Sex dimorphism of pelvic morphological traits has been documented across different human populations, and it is also considered as a sex-determining method. This study shows that the utilization of iliac associated morphological characteristic measurements is less reliable when applied to sex assessment because the attribution of sex dimorphism is demonstrated less within this bony segment. As a result, these measurements require further investigation and the expansion of this analytical method into the different populations to validate the usefulness of these sex indicators in a forensic application.[26]

The effect of sample size is another aspect to consider in this situation. The requirement of cross-validation study using different populations is necessary to evaluate the discriminant outcomes established from these present classification functions. The use of approximately 400 individuals in this study can affect prediction accuracy and increase technical errors. As a result, it is feasible that increased samples will reduce undesirable errors and improve efficiency.

In summary, the consideration of factors affecting prediction accuracy and classification errors for pelvic sex estimation is critical because this bone is under hormonal regulation rather than mechanical influence. These functions may be beneficial where the population of origin of the unidentified skeleton is unknown. Further research is required on cooperative group data from other divergent populations, both in the pelvis region and other skeletal parameters that express sexually dimorphic characteristics.

CONCLUSION

Identifying sex from skeletal remains is a crucial step in human identification. Although human pelvic bone has been the most crucial determinant in this process, only a few anthropologic methods can influence sex determination accuracy. Promoting alternative morphological assessment methods, such as digital evaluation and direct morphometric measurement, as well as direct morphological interpretation from this bone, may be shown to be the most accurate methods. It is critical to recognize instruments that influence correct prediction in sex discrimination. The selection of an appropriate analytical method is essential because it can affect the whole process of forensic human identification. Therefore, it can minimize the possibility of misidentification.

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