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Pelvic Morphometric Study Based on Sex and Ancestry Among Malaysian Population

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Abstract

Introduction: The pelvic girdle consists of pelvic and sacral bones which is sexually dimorphic because of its contribution to the functional sex differences. Researchers have focused on deriving population-specific standards from multislice computed tomography (CT) scans through analyzes of inter-landmark distances to weight predictor variables and classify an unknown individual into one of several reference populations. *Objective*: This study aims to determine the relationship of morphometric of pelvic girdle with sex and ethnicity among the Malaysian population based on a total of 373 pelvic CT images collected at Kuala Lumpur Hospital. *Method*: The pelvic girdles were segmented from CT images through Mimics Research 17.0 software. Inter-landmark distances were measured with Microsoft 3D Builder. *Results and Discussion*: The relative technical error of measurements were in acceptable range at below 2% for both intra-observer and inter-observer error analyses. Results showed that the most useful sexual dimorphism parameters were acetabulum dimensions and the ilium height. The accuracy of demarcation points generated from the Receiver Operating Characteristics (ROC) curve for these parameters ranged from 83.5% to 89.1%. The success rates were 97.3% and 97.1% for respective male and female classification within the Malaysian population. On the other hand, the ilium transverse length, ilium breadth and pelvic inlet transverse diameter were the most useful ancestry differentiation parameters. These parameters showed highest in average values amongst the Chinese, followed by Malay and Indian segment of the Malaysian population. The comparative classification between Chinese and Indian achieved a higher success rate ranging from 64.5% to 67.2%. *Conclusion*: This population-specific study based on pelvic girdle amongst the Malaysian assist in enhancing the existing database for Forensic Anthropologists and Forensic Radiologists to perform both sex and ancestry estimation on skeletal remains.

Keywords: Forensic Anthropology; Pelvic Girdle; Morphometric Analyzes; Sex Estimation; Ancestry Estimation; Malaysian Population.

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Introduction

Sex Estimation

Biological profiling in anthropological approach comprises sex (male and female), geographical origin or ancestry (Negroid, Caucasian, and Mongoloid), stature, and skeletal age estimations.[1] More than a century ago, Pearson first suggested that craniometrics and subsequently metrics of other skeletons like long bones and shoulder girdle are gradually being applied for sex estimation.[2]. In addition, morphometric and spatial geometric analyzes of the human pelvic girdle has long been studied since four decades ago.[3] This could be mainly due to pelvic morphology is reflected in the primary and secondary sexual characteristics from early in utero to puberty age.[4]

As a part of the human appendicular skeletal system, the pelvic girdle (hip girdle) consists of the paired hip or pelvic bones (os coxae) connected in front at the pubic symphysis through the cartilaginous element.[5] Each pelvic bone is initially made up of three pieces of bones i.e. the blade-shaped ilium, the ischium and the pubis. The pelvic girdle is connected behind by the sacrum at the inferior-most part of the vertebral column as part of the axial skeleton forming the pelvis as shown in Fig. 1. Currently, most sex estimation research has taken on a metric approach using discriminant function analyzes (DFA) or other multivariate quantitative methods.[6,7] However, not all skeletal measurements are equally effective for sex estimation using DFA and the skill of the researcher plays an important role as population variation is still a crucial factor.[4]

In the study of sex assessment among the human population, females had generally a broader and flatter pelvis, a wider and shallower pelvic cavity, a wider subpubic angle and smaller acetabula than males.[8] For the univariate discriminant function approach, the success of the pelvis for sex estimation is surprisingly ordinary compared to many other postcranial elements. The accuracy is between 94% and 95.5% for multivariate discriminant function analyzes of all the pelvic measurements.[9] In addition, studies have revealed that ischial length, os-coxal height, and acetabulum diameter are the most sexually dimorphic trait with 83%-86% accuracy.[4] These similar morphometric variables have yielded success rates for the ischiopubic complex of 93% through DFA.[10] Greater sciatic notch (GSN) indexes provide better accuracy at 75% and 87% for Index 1 and Index 2 respectively.[11] Conversely, there is a lack of the similar morphometric approach among the Malaysian population to validate their findings. Having said that, the interaction of sex and ancestry based on pelvic girdle remains unknown, especially among the Malaysian population.

Ancestry Estimation

Anthropological standards for the development of a biological profile are most accurate when applied to the population on which the standard was originally derived. This may be a population based on ancestry, geography, temporal proximity, or multifactorial division.[13] Access to contemporary collections of individuals with known sex is only possible by retrieving and studying living or deceased individuals within a population. Research has confirmed that virtual collections can be applied in lieu of bone for both metric and visual assessment of skeletal traits 14. Several centers of research have focused on deriving population-specific standards from MSCT scans, notably in Europe, Australia, Japan, the United States and India.[13,14]

A large number of laboratories are switching from sliding and spreading calipers towards 3D digitisers and software for the collection of landmark data and inter-landmark distances for further data analyzes in ancestry estimation 13. These inter-landmark distances could be applied in a final analyzes, such as Forensic Discriminant (FORDISC) software and its score in discriminant function analyzes (DFA), to weight the combination of predictor variables and subsequently classify an unknown individual into one of several reference populations.[13,14]

In recent years, the study of human morphological variation has been shifted from selective processes towards the neutral component of shape variation which is mainly due to genetic drift and migration.[15] The major diversity presents usually at local population level between many different geographical regions. Through a morphometric analyzes, literature demonstrated that the shape of both the cranial and os coxae reveal substantial evidence for neutral variation i.e. neutrally evolving phenotypes at a global level.[15,16] The effect of obstetrical constraints has also been revealed in equal extent for both sexes.[15] Thus, population variation in human pelvis might be used to address important theories concerning population history. Since the interaction among ancestry is still unclear, this requires further research as it is rarely mentioned in the literature. This study aims to determine the relationship of pelvic morphometric with sex and ancestry among the Malaysian population.

Materials and Methods

Data sources and acquisition

This was a retrospective cross-sectional study of the pelvic girdle. A total number of 373 CT Scan DICOM folders stored in Picture Archiving and Communication Systems (PACS) from the year 2010 to 2018 were first retrieved retrospectively from the National Institute of Forensic Medicine (NIFM) and the Radiology Department in Kuala Lumpur Hospital (HKL). Postmortem subjects had been scanned by using 2-blocks CT for the whole body using a Toshiba Aquilion 64 Postmortem MSCT scanner whilst living patient subjects had also been selected from diagnostic scans included the CT abdomen, CT pelvic and CT urography with an average resolution of 1.0 mm.

Subject Selection

Subjects were selected based on sex subgroups (Male and Female) and ancestry subgroups (Malay, Chinese and Indian) for each decade subgroup from 10 to 79 years old. They were collected together with their respective known demographic data likewise sex, age, ancestry and height retrievable from the Forensic Medicine Information System (FMIS) or Patient Appointment System (PAS). The chosen age range was to study the relationship of sacrum morphology with the differences onset of puberty for both sexes. There were 27 Males and 27 females in each age subgroups. There was also an equal ratio of ancestry subgroups for each category of sex and age groups. The summary of the subject selection was portrayed as in Table 1. Cases were excluded if the history highlighted conditions or events that could have affected bone morphology of the pelvic girdle after being reviewed by Forensic Radiologist and Anthropologist. For example, pelvic fracture, burning, pelvic anomalies such as tumour or diseases likely to have affected the bone structure were excluded.

Data reconstruction and analyzes

The pelvic bones were viewed and segmented using software Mimic Research 17.0, available at the School of Dental Sciences, Universiti Sains Malaysia, through Multi Planar Reconstruction (MPR) and 3D Image Reconstruction. Linear measurements were taken in centimeter (cm) at 2 decimal points by using the software 3D Builder 17 based on Table 2 and Fig. 2. The measurements for all the subjects were taken twice for the intra-observer error analyzes. Relative technical error of measurement (TEM), which was acceptable if less than 2%, for each parameter was calculated using equation 1 and equation 2.[18] The significant differences for observer measurements were also tested using paired-sample statistical analyzes in Statistical Package for the Social Sciences (SPSS) version 24 with confidence level 95% i.e. $p < 0.05$. The calculation was shown in the equations below:

$$.Absolute\ TEM \sqrt{\frac{\Sigma d_i^2}{2n}}$$ ....Equation 1

Where: Σd2 = summation of deviations raised to the second power

n = number of subjects measures

i = the number of deviations

$$\text{relative TEM} = \frac{\text{TEM}}{\text{VAV}} \times 100$$ ....Equation 2

Where: TEM = Absolute TEM from equation 1 expressed in %

VAV= Average value of the parameters and indexesw

Statistical analyzes

The Kolmogorov-Smirnov test ($N > 100$) was first conducted to determine normality at $p > 0.05$ of all the parameters. Statistical analyzes had been conducted to determine the significant difference at $p < 0.05$ between sex and ancestry among the Malaysian population by using Independent t-test and Analyzes of Variance (ANOVA) test respectively. The demarcation points for the respective parameters with a significant difference had been identified at an optimum level for sex estimation based on the Receiver Operating Characteristic (ROC) curve analyzes. Classification for sex and ancestry were conducted by using Discriminant Function Analyzes (DFA) and clustering analyzes for each of the significant parameters as well as the combination of the significant parameters. Finally, Multivariate Analyzes of Variance (MANOVA) was performed to determine the relationship between pelvic morphometrics with sex and ancestry among the Malaysian population.

Results and Discussion

There was a total of eight parameters measured for biological profiling in this study. Descriptive statistics for the overall selected subjects had been listed in Table 3. Kolmogorov-Smirnov (K-S) test showed that normality was assumed at $p > 0.05$ for pubic inlet transverse diameter (P2), pubic height (P4) and ilium height (P6) only. However, the boxplots of all parameters were normally distributed with the central spread of the parameter measurements (Fig. 3). In short, the normality test had generally conceded and parametric statistical analyzes could be conducted for further analyzes in this study.

The patterns of bilateral symmetry of through pelvic morphometric analyzes on the pubic inlet longitudinal diameter (P3), pubic height (P4), ilium dimensions (P5 and P6) and acetabulum dimensions (P7 and P8) were studied. From the results shown in Table 4, there was a significant difference between the right side and the left side of the pelvic ($p < 0.05$) except ilium height (P6) and acetabulum width (P7).

The control of the precision and accuracy of the measurements was crucial in the anthropometry field. Hence, Kevin Norton's and Tim Old's methodology had been applied in several previous studies by computing the technical error of measurements (TEM) as well as the coefficient of reliability.[18,20,21] In this study, duplicate readings for each of the parameters were taken by the observer to compensate for the intra-observer error. There was no significant difference between reading 1 and reading 2 for both observers based on the paired sample t-test at $p > 0.05$.

Furthermore, Table 5 showed the summary of the inter-observer analyzes on each of the parameters measured by using 35 randomly selected subjects. The relative TEM for all the parameters was in a generally acceptable range at below 3% and reliability at higher than 0.90. In short, these error analyses had confidently shown that the morphometric data generated from the points chosen for landmarking (Fig. 2 and Table 2) were precise and reliable.

Sex Estimation

A total of 188 males and 185 females had been selected for the sex estimation analyzes based on the parameters as shown in Table 6. There were significant differences between sexes at $p < 0.05$ for all the parameters except P1 with $t(358) = 0.500$, $p = 0.618$. Hence, sexual dimorphism could not be observed in the ilium transverse length and would not be considered for sex classification analyzes.

From the descriptive statistics and independent t-test analyzes, females had higher values in pubic inlets dimensions (P2 and P3) compared to males. This indicated that females had significantly bigger pubic inlets at both transverse and longitudinal diameters. However, males had higher values in ilium measurements (P1, P5 and P6), pubic height (P4) and acetabulum dimensions (P7 and P8) compared to females.

The demarcation points of each parameter with the significant differences between sexes had been determined by using Receiver Operating Characteristic (ROC) curve analyzes as shown in Fig. 4. These demarcation points as listed in Table 7 were population specific and different from other population and database, thus they could be used for sex estimation among Malaysian population at the accuracy ranging from 48.59% to 89.13% for each individual parameter. The most useful sexual dimorphism parameters were the ilium height (P6) as well as the acetabulum dimensions (P7 and P8).

From the summary of canonical discriminant function (CDF) analyzes for sex classification, the obtained eigenvalue was 4.095 with canonical correlation at 0.897, Wilk's lambda at 0.196 and 2 (7, N = 358) = 573.945, $p < 0.001$. This classification was conducted based on the combination of all the parameters (P2-P8) with a significant difference between sexes as shown in Table 8.

Based on the CDF analyzes, the predicted group membership for the combination of parameters (P2-P8) had shown 97.3% and 97.1% success rate for male and female classification respectively even for leave-one-out cross validation study among Malaysian population as presented in Table 9, Fig. 5 and Fig. 6.

From the results displayed in Table 10, two clusters had been generated showing good quality of sex clustering at the average silhouette of 0.6 through the pelvic morphometric of P2-P8 parameters by using a two-step clustering analyzes for sex estimation. Based on the cluster weightage analyzes, the most useful sexual dimorphism parameters were the acetabulum dimensions (P7 and P8) at 0.80 in average and ilium height (P6) at 0.71 in which consistent with classification results.

Ancestry Estimation

A total of 126 Malay, 125 Chinese and 122 Indian had been selected for the ancestry estimation analyzes based on the parameters as shown in Table 11. There were significant differences among ancestry at $p < 0.05$ for pubic inlets (P2 and P3), ilium breadth (P5) and acetabulum height (P8) especially between Chinese and Indian through post-hoc ANOVA test. The true significant difference among all the three ancestry of Malaysian population had been identified on ilium transverse length (P1) at F (2,359) = 9.729, $p < 0.001$. All these parameters in average showed similar patterns of pelvic morphometric whereby Chinese possessed higher average morphometric values, followed by Malay while Indian possessed the lowest values among them except pubic height (P4) that was not significantly different.

From the summary of CDF analyzes for ancestry classification, the obtained function 1 (F1) and function 2 (F2) were at □2 (10, N = 359) = 33.052, $p < 0.001$ and □2 (4, N = 359) = 4.437, p = 0.350 respectively. This classification was conducted based on the combination of the parameters P1-P3, P5 and P8 with a significant difference among ancestry. Based on the CDF analyzes, the predicted group membership for the combination of parameters (P1-P3, P5 and P8) had shown 25.4%, 53.7% and 56.0% success rate for Malay, Chinese and Indian classification respectively among Malaysian population as shown in Table 12 and Fig. 7. Classification between Chinese and Indian had achieved a higher success rate range from 63.8%–67.8% including the leave-one-out cross validation study.

From the results shown in Table 13, three clusters had been generated through the pelvic morphometric of P1-P3, P5 and P8 parameters by using a two-step clustering analyzes for ancestry estimation. Based on the cluster weightage analyzes, the most useful ancestry differentiation parameters were ilium transverse length (P1) and ilium breadth (P5) at 0.05 and 0.04 respectively in which consistent with their ANOVA results. Further analyzes had been conducted by using these two most important parameters (P1 and P5) and the results showed good quality of ancestry clustering at the average silhouette of 0.6.

Multivariate Analyzes

From the multivariate analyzes of MANOVA, as shown in Table 14, none of the parameters of pelvic morphometrics were affected by the interaction between the other variables including sex, ancestry and age. Thus, any combination of the biological profiling variables did not significantly affects the pelvic morphometric. In summary, most useful sexual dimorphism parameters were ilium height (P6) and the acetabulum dimensions (P7 and P8) whilst the most useful ancestry differentiation parameters were ilium transverse length (P1) and ilium breadth (P5).

Discussion

The standard of relative technical error of measurements (TEM) should be below 1.5% for intra-observer analyzes.[18,21] However, the relative TEM for all the parameters was generally in an acceptable range which is below 2% when all the 373 subjects were included for the error analyzes.[18]. Although some of the parameters did not achieve the ideal standard for example pubic height (P4), it did not deviate much from the standard and

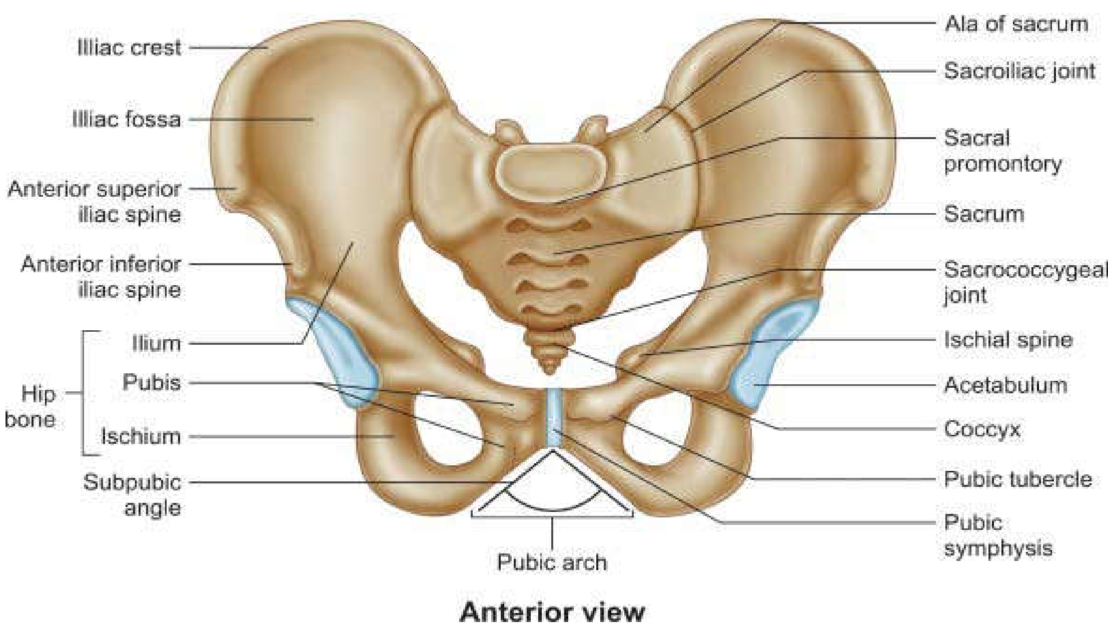

Fig. 1: Anatomical illustration of the pelvic girdle and pelvis [12]

Table 1: Subject distribution across sex, age and ancestry subgroups

Age groups	Sex groups	Ancestry subgroups			Total
		Malay	Chinese	Indian	
10-19	Male	9	9	9	27
	Female	9	8	6	23
20-19	Male	9	9	9	27
	Female	9	9	9	27
30-39	Male	9	9	9	27
	Female	9	9	9	27
40-49	Male	9	9	9	27
	Female	9	9	9	27
50-59	Male	9	9	9	27
	Female	9	9	9	27
60-69	Male	9	9	9	27
	Female	9	9	9	27
70-79	Male	9	9	8	26
	Female	9	9	9	27
Subtotal	Male	63	63	62	188
	Female	63	62	60	185
	Total	126	125	122	373

Table 2: Definition and description of pelvic girdle parameters modified based on Lia, Noreen, Andrea, Stephen [15] and Kanika, Rajan, Gurdeep, Gaurav [19]

No.	Parameter(s)	Description
P1	Ilium Transverse Length	Transverse diameter width of two apex of the antero-superior right and left iliac spine.
P2	Pubic Inlet Transverse Diameter	Maximum central distance of the widest margins of the pubic inlet.
P3	Average pubic Inlet Longitudinal Diameter	Distance from the midpoint of sacral body (S1) to the most superior point on the superior edge of the medial aspect of the pubic symphysis.
P4	Average pubic Height	Distance between the most superior and most inferior point on the inferior edge of the medial aspect of the pubic symphysis.
P5	Average ilium Breadth	Distance between apex of the postero-superior illiac spine and apex of the antero-superior illiac spine.
P6	Average ilium Height	Distance between the most superior point of the illiac crest and the farthest point of ischial curve.
P7	Average acetabulum Width	Maximum diameter of the points on the acetabulum margin corresponding to where ilium and ilio-pubic ramus meet.
P8	Average acetabulum Height	Maximum diameter of the most inferior points of the anterior end of the lunate surface of the acetabulum.

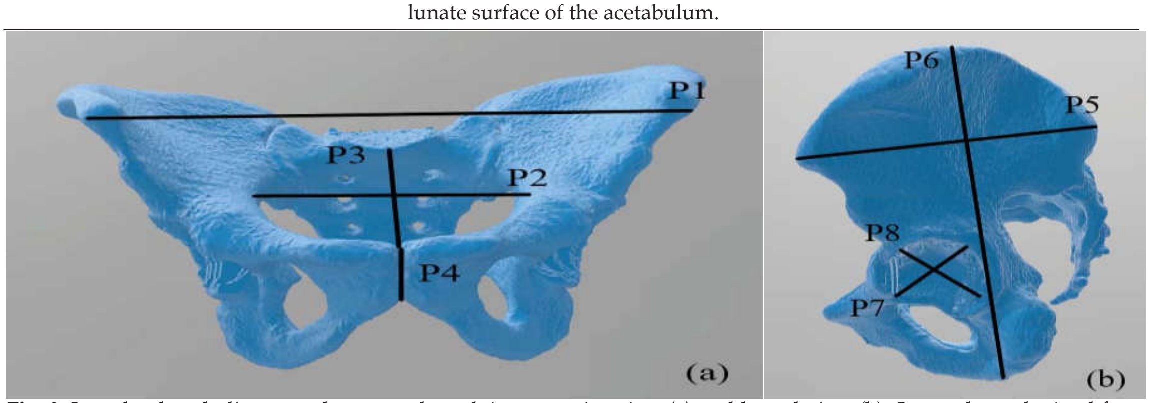

Fig. 2: Inter-landmark distances shown on the pelvic at anterior view (a) and lateral view (b). Screenshots obtained from Microsoft 3D Builder software.

Table 3: Descriptive statistics for parameters of pelvic morphometric

No.	N	Minimum –Maximum	Mean ± Standard Error	Standard Deviation	K-S Test Sig. Value
P1	360	15.29 – 26.97	22.79 ± 0.10	1.81	0.032
P2	363	7.56 – 14.01	11.80 ± 0.05	0.96	0.064*
P3	365	8.60 – 14.02	11.35 ± 0.06	1.07	0.042
P4	371	1.82 – 4.59	3.11 ± 0.02	0.40	0.200*
P5	370	10.18 – 17.22	14.58 ± 0.05	1.01	0.000
P6	366	14.90 – 23.96	19.56 ± 0.07	1.38	0.200*
P7	372	3.86 – 5.59	4.73 ± 0.02	0.37	0.001
P8	372	3.89 – 5.75	4.77 ± 0.02	0.37	0.014

Note: unit in centimetre (cm); * represents p > 0.05 whereby normality is assumed

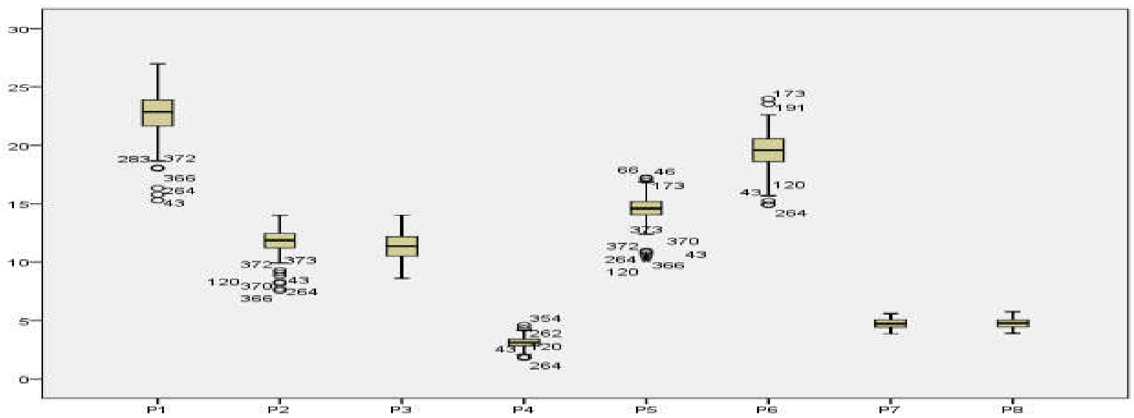

Fig. 3: Boxplots for pelvic morphometric parameters.

Table 4: Paired sample statistics for symmetry analyzes of pelvic morphometrics

No.	N	Paired Samples Correlation	Correlation Sig. Value	t value	Paired Samples Sig. Value
Pair 1: P3R and P3L	363	0.997	<0.001	-3.501	0.001*
Pair 2: P4R and P4L	371	0.955	<0.001	3.225	0.001*
Pair 3: P5R and P5L	364	0.936	<0.001	3.992	<0.001*
Pair 4: P6R and P6L	361	0.977	<0.001	-0.629	0.530
Pair 5: P7R and P7L	367	0.866	<0.001	0.376	0.707
Pair 6: P8R and P8L	367	0.876	<0.001	21.569	<0.001*

Note: * represents p < 0.05 whereby significant difference is assumed

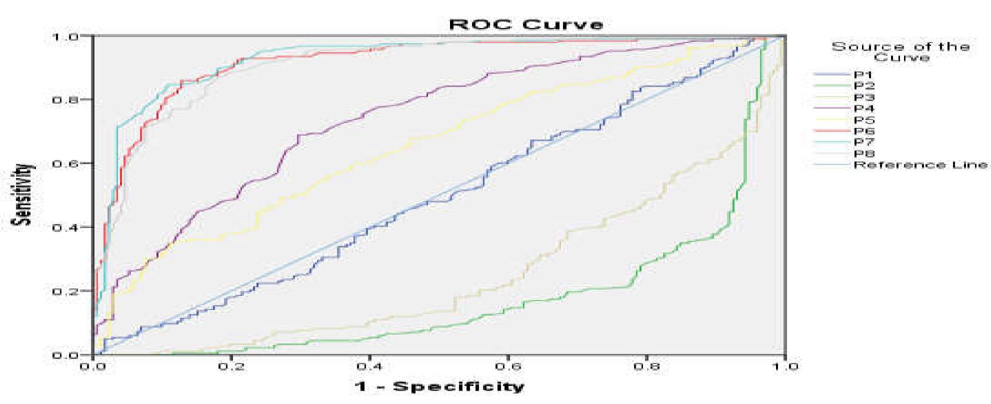

Fig. 4: Receiver Operating Characteristic (ROC) curve analyzes for pelvic morphometric parameters

Table 5: Inter-observer analyzes by using 35 randomly selected subjects

No.	Mean ± Standard Deviation (cm)			Relative TEM (%)	CR	Paired Samples Sig. Value
	Observer 1	Observer 2	Average			
P1	22.71 ± 1.93	22.86 ± 1.64	22.78 ± 1.62	0.8556	0.9856	0.772
P2	11.69 ± 1.07	11.68 ± 0.83	11.68 ± 0.82	0.7985	0.9872	0.601
P3R	11.30 ± 1.13	11.35 ± 1.29	11.33 ± 1.29	1.1420	0.9899	0.996
P4R	3.17 ± 0.58	3.14 ± 0.45	3.16 ± 0.45	2.2163	0.9756	0.873
P5R	14.59 ± 0.95	14.56 ± 0.85	14.58 ± 0.85	1.8530	0.9001	0.925
P6R	19.49 ± 1.56	19.37 ± 1.15	19.49 ± 1.21	1.1198	0.9675	0.495
P7R	4.65 ± 0.35	4.64 ± 0.38	4.65 ± 0.38	1.6353	0.9610	0.723
P8R	4.84 ± 0.30	4.82 ± 0.35	4.83 ± 0.34	1.8853	0.9280	0.524
P3L	11.30 ± 1.13	11.40 ± 1.30	11.35 ± 1.29	1.4081	0.9846	0.706
P4L	3.18 ± 0.70	3.14 ± 0.42	3.16 ± 0.43	2.6203	0.9621	0.552
P5L	14.57 ± 1.11	14.58 ±0.80	14.57 ± 0.80	1.5362	0.9216	0.818
P6L	19.51 ± 1.75	19.50 ± 1.25	19.51 ± 1.27	0.7419	0.9871	0.983
P7L	4.68 ± 0.35	4.63 ± 0.40	4.65 ± 0.39	2.1146	0.9369	0.314
P8L	4.61 ± 0.25	4.57 ± 0.38	4.59 ± 0.39	2.2157	0.9329	0.392

Note: * represents $p < 0.05$ whereby significant difference is assumed; CR represents coefficient of reliability that can be calculated with equation $R = 1 - (\text{Absolute TEM})^2 / (SD)^2$

Table 6: Descriptive statistics for parameters and indexes of pelvic morphometric based on sex

No.	Sex	N	Minimum – Maximum	Mean ± Standard Error	Standard Deviation	Independent t-test Sig. Value
P1	Male	183	15.77 – 26.46	22.84 ± 0.13	1.71	0.618
	Female	177	15.29 – 26.97	22.74 ± 0.14	1.92	0.960 [T]
P2	Male	186	7.71 – 13.33	11.37 ± 0.05	0.72	<0.001*
	Female	177	7.56 – 14.01	12.25 ± 0.07	0.96	
P3	Male	187	8.60 – 13.02	10.89 ± 0.07	0.95	<0.001*
	Female	178	9.11 – 14.02	11.83 ± 0.07	0.97	<0.001* [T]
P4	Male	188	1.83 – 4.59	3.27 ± 0.03	0.38	<0.001*
	Female	183	1.82 – 3.93	2.94 ± 0.03	0.36	
P5	Male	188	10.62 – 17.22	14.84 ± 0.07	0.93	<0.001*
	Female	182	10.18 – 16.66	14.32 ± 0.08	1.02	<0.001* [T]
P6	Male	188	15.23 – 23.96	20.45 ± 0.08	1.05	<0.001*
	Female	178	14.90 – 21.48	18.62 ± 0.08	1.01	
P7	Male	188	3.91 – 5.59	5.00 ± 0.02	0.27	<0.001*
	Female	184	3.86 – 5.31	4.46 ± 0.02	0.25	<0.001* [T]
P8	Male	188	3.89 – 5.75	5.02 ± 0.02	0.27	<0.001*
	Female	184	3.89 – 5.23	4.51 ± 0.02	0.26	<0.001* [T]

Note: unit in centimetre (cm); * represents $p < 0.05$ whereby significant difference is assumed; represents Mann-Whitney U test significant value; higher average values are in bold

Table 7: Demarcation points of pelvic morphometric with the respective accuracy for sex estimation

No.	Sex	N	Mean ± Standard Deviation	DP	Within Range (n)	Accuracy (%)
P1	Male	183	22.84 ± 1.71	>22.825	90	49.18%
	Female	177	22.74 ± 1.92	<22.825	86	48.59%
P2	Male	186	11.37 ± 0.72	<11.885	145	77.96%
	Female	177	12.25 ± 0.96	>11.885	136	76.84%
P3	Male	187	10.89 ± 0.95	<11.525	137	73.26%
	Female	178	11.83 ± 0.97	>11.525	111	62.36%
P4	Male	188	3.27 ± 0.38	<3.095	130	69.15%
	Female	183	2.94 ± 0.36	>3.095	127	69.40%
P5	Male	188	14.84 ± 0.93	>14.440	127	67.55%
	Female	182	14.32 ± 1.02	<14.440	98	53.85%
P6	Male	188	20.45 ± 1.05	>19.555	161	85.64%
	Female	178	18.62 ± 1.01	<19.555	154	86.52%
P7	Male	188	5.00 ± 0.27	>4.735	159	84.57%
	Female	184	4.46 ± 0.25	<4.735	164	89.13%
P8	Male	188	5.02 ± 0.27	>4.765	161	83.51%
	Female	184	4.51 ± 0.26	<4.765	153	84.24%

Note: unit in centimetre (cm); DP represents demarcation points based on optimum level from ROC curve by using the reference line; higher average values are in bold

Table 8: Canonical discriminant function (CDF) analyzes for sex classification

No.	Unstandardised coefficients	Standardised coefficients	Pooled within group correlation
P2	1.038	0.862	-0.524
P3	0.596	0.575	-0.477
P4	0.467	0.172	-0.446
P5	-0.046	-0.044	0.272
P6	-0.977	-1.010	0.241
P7	-1.233	-0.320	-0.220
P8	-0.322	-0.086	-0.137
(Constant)	6.710		

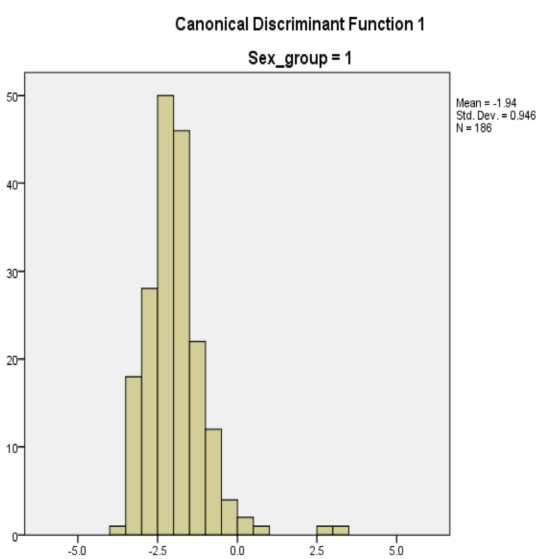

Fig. 5: Discriminant Function Analyzes for males by using P2-P8

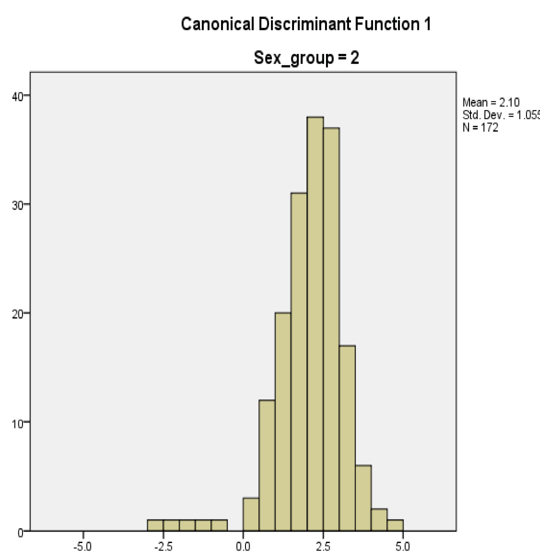

Fig. 6: Discriminant Function Analyzes for females by using P2-P8.

Table 9: Classification results for sex discriminant function analyzes by using P2-P8

No.	Sex	Male	Female	Total
Count	Male	181	5	186
	Female	5	167	172
%	Male	97.3%	2.7%	100.0%
	Female	2.9%	97.1%	100.0%

Note: Predicted group with 97.2% of original grouped cases correctly classified

Table 10: Two-step clustering analyzes of pelvic morphometric for sex estimation

No.	Cluster Weightage	Cluster 1 Mean ± SD (cm) (N = 181)	Cluster 2 Mean ± SD (cm) (N = 161)	Combined Mean ± SD (cm) (N = 342)
P2	0.24	12.24 ± 1.00	11.39 ± 0.67	11.80 ± 0.95
P3	0.23	11.83 ± 0.99	10.89 ± 0.94	11.35 ± 1.07
P4	0.23	2.94 ± 0.37	3.29 ± 0.36	3.12 ± 0.40
P5	0.11	14.29 ± 1.03	14.88 ± 0.87	14.59 ± 1.00
P6	0.71	18.57 ± 1.05	20.53 ± 0.92	19.57 ± 1.39
P7	0.86	4.45 ± 0.25	5.01 ± 0.24	4.74 ± 0.38
P8	0.73	4.51 ± 0.26	5.04 ± 0.25	4.78 ± 0.37
Sex	Male	N = 3 (1.6%)	N = 183 (98.4%)	N = 186 (100.0%)
	Female	N = 172 (100.0%)	N = 0 (0%)	N = 172 (100.0%)

Table 11: Descriptive statistics for parameters of pelvic morphometric based on ancestry

No.	Sex	N	Minimum–Maximum	Mean ± Std Error	Standard Deviation	ANOVA test Sig. Value
P1	Malay	123	15.29 – 26.97	22.88 ± 0.16	1.79	<0.001*
	Chinese	121	16.33 – 26.76	23.23 ± 0.17	1.83	<0.001* ^{T}
	Indian	116	15.77 – 25.43	22.23 ± 0.16	1.68	
P2	Malay	124	8.19 – 14.01	11.86 ± 0.09	0.91	0.007*
	Chinese	122	7.56 – 13.98	11.95 ± 0.09	0.94	
	Indian	117	7.71 – 13.55	11.58 ± 0.09	0.94	
P3	Malay	124	8.60 – 13.87	11.38 ± 0.09	1.05	0.016*
	Chinese	123	9.11 – 14.02	11.52 ± 0.09	1.04	0.009* ^{T}
	Indian	118	9.14 – 13.86	11.13 ± 0.10	1.08	
P4	Malay	124	1.82 – 4.10	3.08 ± 0.03	0.39	0.292
	Chinese	125	2.16 – 4.59	3.16 ± 0.04	0.42	
	Indian	122	1.83 – 4.33	3.09 ± 0.04	0.40	
P5	Malay	123	10.18 – 17.16	14.53 ± 0.09	1.03	0.001*
	Chinese	125	10.41 – 17.22	14.84 ± 0.09	0.99	<0.001* ^{T}
	Indian	122	10.62 – 16.39	14.37 ± 0.09	0.95	
P6	Malay	123	14.90 – 22.53	19.48 ± 0.13	1.42	0.158
	Chinese	123	16.22 – 23.96	19.75 ± 0.12	1.35	
	Indian	120	15.23 – 22.32	19.44 ± 0.12	1.37	
P7	Malay	125	3.86 – 5.56	4.71 ± 0.03	0.37	0.073
	Chinese	125	3.91 – 5.59	4.79 ± 0.03	0.37	0.079 ^{T}
	Indian	122	3.90 – 5.52	4.69 ± 0.03	0.37	
P8	Malay	125	3.89 – 5.48	4.73 ± 0.03	0.36	0.002*
	Chinese	125	3.89 – 5.75	4.87 ± 0.03	0.35	0.003* ^{T}
	Indian	122	4.07 – 5.62	4.72 ± 0.03	0.36	

Note: unit in centimetre (cm); * represents $p < 0.05$ whereby significant difference is assumed; ^{T} represents Kruskal Wallis test significant value

Table 12: Classification results for ancestry discriminant function analyzes by using parameters P1-P3, P5 and P8

No.	Sex	Malay	Chinese	Indian	Total
Count	Malay	31	43	48	122
	Chinese	20	65	36	121
	Indian	22	29	65	116
%	Malay	25.4%	35.2%	39.3%	100.0%
	Chinese	16.5%	53.7%	29.8%	100.0%
	Indian	19.0%	25.0%	56.0%	100.0%

Note: Predicted group with 44.8% of original grouped cases correctly classified

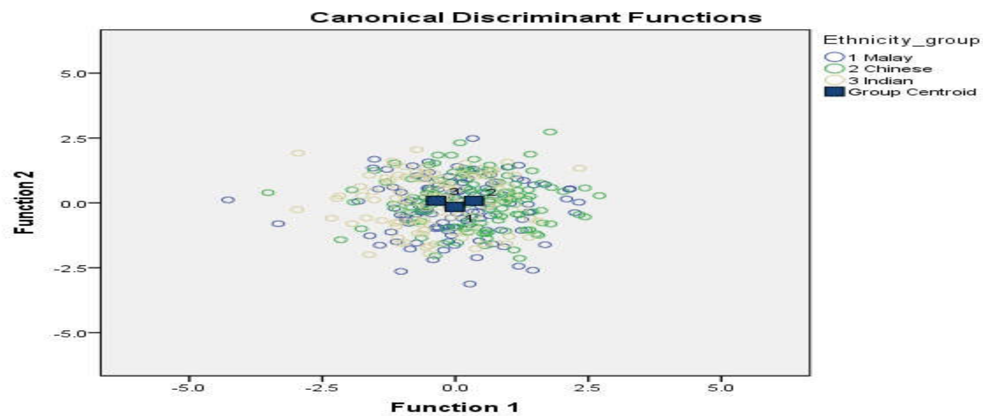

Fig. 7: Discriminant Function Analyzes for ancestry by using parameters P1-P3, P5 and P8

Table 13: Two-step clustering analyzes of pelvic morphometric for ancestry estimation

No.	CW	Cluster 1 Mean ± SD (cm) (N = 118)	Cluster 2 Mean ± SD (cm)(N = 114)	Cluster 3 Mean ± SD (cm) (N = 122)
P1	0.05	22.07 ± 1.90	23.32 ± 1.68	23.00 ± 1.62
P2	0.03	11.47 ± 1.11	12.03 ± 0.80	11.93 ± 0.84
P3	0.01	11.12 ± 1.08	11.52 ± 1.05	11.42 ± 1.04
P5	0.04	14.24 ± 1.18	14.90 ± 0.84	14.61 ± 0.88
P8	0.02	4.71 ± 0.38	4.88 ± 0.35	4.74 ± 0.36
Ancestry	Malay	N = 2 (1.6%)	N = 0 (0%)	N = 120 (98.4%)
	Chinese	N = 2 (1.7%)	N = 119 (98.3%)	N = 0 (0%)
	Indian	N = 116 (100.0%)	N = 0 (0%)	N = 0 (0%)

Note: CW represents cluster weightage

Table 14 Multiple Analyzes of Variances (MANOVA) test of pelvic morphometric to study interaction across sex, ancestry and age

No.	Sex*Ancestry		Sex*Age		Ancestry*Age		Sex*Ancestry*Age	
	F	Sig.	F	Sig.	F	Sig.	F	Sig.
P1	0.026	0.974	1.872	0.085	0.659	0.791	0.251	0.995
P2	0.639	0.528	2.073	0.056	0.452	0.940	0.670	0.780
P3	1.551	0.214	1.155	0.330	1.307	0.213	0.612	0.832
P4	1.032	0.357	0.928	0.475	1.797	0.048	1.100	0.360
P5	0.225	0.798	1.569	0.156	0.983	0.465	0.745	0.707
P6	0.004	0.996	0.558	0.764	1.433	0.149	0.676	0.775
P7	1.022	0.361	1.408	0.211	0.678	0.773	0.744	0.708
P8	1.705	0.184	1.336	0.240	0.557	0.876	1.058	0.395

Note: * represents $p < 0.006$ (0.05/8 parameters) whereby significant multivariate interaction are assumed.

computed at below 2%. In order to compensate for this limitation, further reliability analyzes was in the range of good category as at above 0.95 for all the parameters.[20] Another limitation was extra caution had to be taken against sacral promontory landmark of the subjects presenting with sacralisation especially when measuring the pubic inlet longitudinal diameter. Hence, the quality control adhered in this study should be sufficiently effective to make sure the reliability and precision of the data were at par with the standard in anthropometry analyzes.

The pelvic girdle was bilaterally asymmetry as mentioned by Kurki[22] whereby its morphology could be subject to multiple selective factors including obstetrics, bipedal locomotion and environmental factors such as occupational or biomechanical loading effect. Our findings concurred with Boulay, Tardieu, Bénaim, Hecquet, Marty, Prat Pradal, Legaye, Duval Beaupère, Pélissier[23] whereby pelvic asymmetry was encountered especially in the area of iliac blades, iliac breadth and superior lunate surface of acetabulum. As such, both sides of the pelvic were required to be measured so as to contemplate the bilateral asymmetry of the pelvic and average of both sides should be considered for further analyzes.

On the other hand, we also could deduce that males had significantly bigger ilium bones and acetabulum size. These findings were supported by the previous studies in different populations, for example Hamann-Todd collections, American Whites, European, Indian and many more.[8,16,24-26] The sexual dimorphism was contributed by the sex-biased expression of autosomal genes and could be regulated by sex-specific hormone levels and the sensitivity of its receptors.[24] The pelvic morphology was also exposed to differential selection pressures for obstetric and bipedal locomotion in both males and females.[8]

From the classification based on sex, we had concurred with the findings by By the way, Ross [27] through a geometry morphometric analyzes whereby pelvic bones had recorded accuracy rate ranging from 98% to 100% for sex estimation among African and European Americans. However, the ancestry prediction power with these parameters was quite low. From a geometric morphometric study, By the way, Ross[27] had reported European American may be less sexually dimorphic compared to African American. However there was no comparison and classification between ancestries being conducted by the previous studies.

Conclusion

In conclusion, most useful sexual dimorphism parameters were ilium height (P6) and the acetabulum dimensions (P7 and P8). The accuracy of demarcation points generated from the ROC curve for these parameters was ranging from 83.5%-89.1%. Females had significantly bigger pubic inlets at both transverse and longitudinal diameters whilst males had significantly bigger ilium size (P1, P5 and P6), pubic height (P4) and acetabulum dimensions (P7 and P8). In the combination of parameters (P2-P8), the success rates were 97.3% and 97.1% for male and female classification respectively among the Malaysian population.

The ilium transverse length (P1) and ilium breadth (P5) were the most useful ancestry differentiation parameters. These parameters in average were highest among Chinese, followed by Malay and the lowest in Indian. In the combination of parameters P1-P3, P5 and P8, the lower success rates were observed as at 25.4%, 53.7% and 56.0% for Malay, Chinese and Indian classification respectively. However, the classification between Chinese and Indian by using inter-landmark distance had achieved a higher success rate ranging from 64.5%–67.2%.

To conclude, this population-specific study based on pelvic bones among Malaysian helps to enhance the existing database for Forensic Anthropologists and Forensic Radiologists to perform both sex and ancestry estimation. In the future, researchers of a similar area of interest are recommended to explore more on the geometric morphometric based on the parameters and landmarks developed in this study. From the geometric morphometric study, three-dimensional coordinates could be more extensively differentiated for biological profiling. New parameters could also be explored into other bony parts of the pelvic bones up to the extension of the entire pelvis, especially for sexual dimorphism study. Since only three main ancestry of Malaysian are included in this study, more Malaysian ancestry could be studied in future researches as well. Virtual anthropology is beneficial to the scientific community and hence researchers could be extensively involved in this field by using other skeleton parts throughout the human body to enhance the study significance.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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