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# Stature estimation study based on pelvic and sacral morphometric among Malaysian population

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## Abstract

**Background:** Virtual anthropology in estimating stature through multislice computed tomography scanning is important for forensic cases and mass disasters. Regression formulae generated directly from other post-cranial skeleton parts can be applied for estimating stature. Literatures have revealed that scoring of pelvic shape in both sexes is significantly correlated with stature. Hereafter, this study aims to correlate the pelvic and sacral morphometric with stature based on sex and ancestry among the Malaysian population from the selected samples of 373 CT images at Kuala Lumpur Hospital. The three-dimensional pelvic girdles were first segmented from CT images through Mimics Research 17.0 software. Inter-landmark distances were measured with Microsoft 3D Builder and their respective indexes were computed.

**Results:** This study showed that the auricular lengths, ilium dimension and acetabulum were the most useful stature estimator at  $R > 0.5$ . The combination of pelvic parameters, sacral parameters and indexes had contributed to a higher  $R^2$  value of the regression models.

**Conclusions:** Pelvic morphometric was generally a better stature estimator compared to sacral morphometric. The population-specific formula produced from this study should only be realistic within the Malaysian population. This helps to enhance the existing references for stature estimation especially when incomplete human remains are discovered.

**Keywords:** Forensic anthropology, Pelvic, Sacrum, Stature estimation, Malaysian population

## Background

Biological profiling in anthropological methodology encompasses estimation of sex (male and female), ancestry or geographical ancestry (African, European and Asian), skeletal stature and age-at-death estimation (Linda 2006). The advancement of virtual anthropology has been designated with multi-slice three dimensional (3D) rendered computed tomography (CT) scanning. This is easily available to most forensic anthropologists who are practicing in the forensic mortuary, for example

at Kuala Lumpur Hospital, Malaysia (Khoo and Mohd Shah 2014).

Stature estimation was first steered during the middle of the eighteenth century by Jean-Joseph Sue and further established by Carl Pearson (Megan and Ann 2013). Living stature is demarcated as the maximum height reached during a person's lifetime and may be anticipated only after age, sex, and ancestry have been evaluated. This is due to varying levels of growth, skeletal degeneration, sexual dimorphism, and population variation (Megan and Ann 2013; Wiley 2016). Estimating stature is part of the identification process in mass disasters and forensic cases to assist the police in death investigation (Özaslan et al. 2003).

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Although both whole-limb-bone and whole-skeleton methods are usually utilised for stature estimation, nonetheless, it is restricted in situations where the complete bones may be absent and bodies are fragmentary (Wiley 2016). Hence, the remedy of this situation is by applying regression formula using the length of other body parts (Megan and Ann 2013; Wiley 2016). For example, stature estimation is well established by means of the length of long bones especially lower limbs (Wiley 2016). Regression formulae have also been calculated for estimating stature directly from cranium, vertebrae, clavicle, scapula, sternum, pelvis, foot, hand bones and other parts of the body since the early 1980s (Wiley 2016).

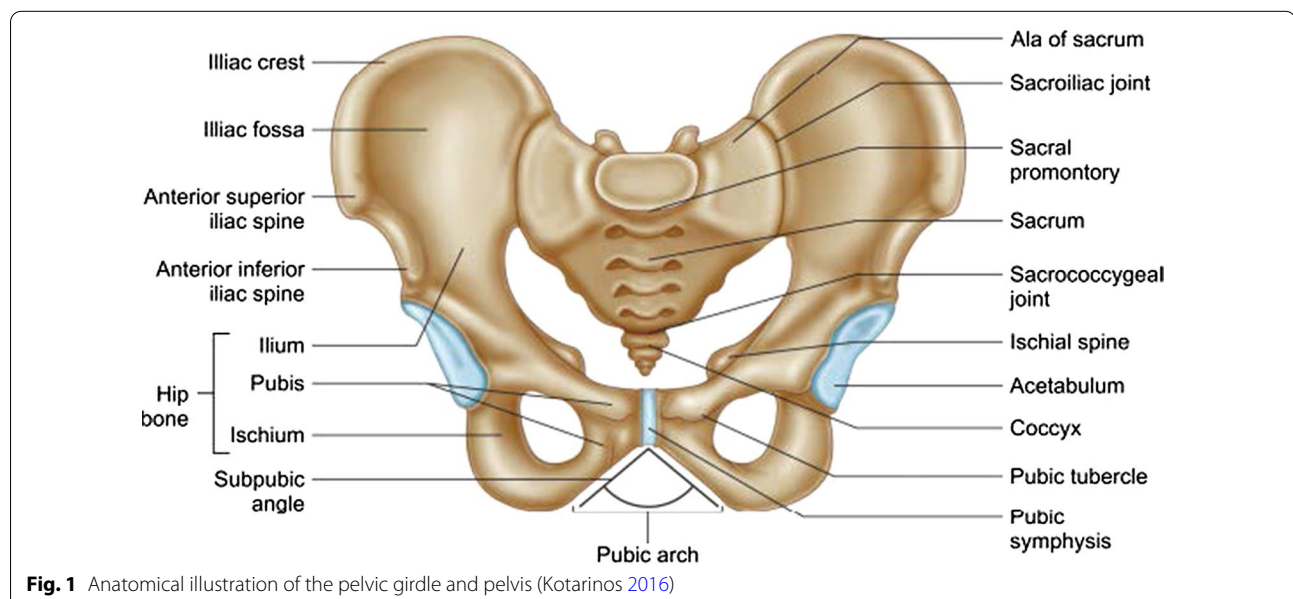
The pelvic girdle, as a part of the human appendicular skeletal system, consists of the paired pelvic bones or os coxae whereby is articulated anteriorly through the cartilaginous element at the pubic symphysis (Standing 2015). It is also articulated posteriorly with the sacrum as part of the axial skeleton at the inferior-most part of the vertebral column forming the pelvis as shown in Fig. 1.

Pelvic shape score is significantly correlated with the stature in both sexes among Hamann-Todd collection (Barbara and Philipp 2015). Taller individuals have a relatively higher and narrower pelvis with a more oval pelvic inlet and a more forward projecting symphysis compared to shorter individuals with rounder pelvic cavity (Barbara and Philipp 2015; Megan and Ann 2013). On average, taller persons have longer iliac blades and a shorter relative distance between the acetabula compared with shorter persons (Barbara and Philipp 2015; Wiley 2016). Both margins between iliac spines to ischial spines and iliac spines to ischial

tuberosities are very strongly correlated with stature (Torimitsu et al. 2015). This correlation is stronger in males compared to females. This is also applicable to sacrum height and pubic symphysis length (Barbara and Philipp 2015; Pelin et al. 2005; Torimitsu et al. 2014, 2015).

On the other hand, there are also a few studies on sacrum height using the images of magnetic resonance imaging (MRI) and multi-slice CT applying for stature estimation (Hakki et al. 2011; Pelin et al. 2005; Torimitsu et al. 2014). As study showed that sacrum height in males is significantly higher than in females (Hakki et al. 2011; Torimitsu et al. 2014). The correlation between sacral height and the stature is reported as only significant in males (Hakki et al. 2011). In contrary, Torimitsu et al. (2014) reported a positive correlation in both sexes, however, all these studies revealed a comparatively moderate regression coefficient ranging from 0.4 to 0.6 only. Multiple regression equations could be designed from plenty of parameters to improve these regression coefficient,  $R^2$  (Pelin et al. 2005).

In spite of numerous stature formulae that have been developed for worldwide populations, these equations cannot be applied in the Malaysian population as regression formulae are generally population specific. There is always the necessity for additional population-specific reference data through regression theory and mathematical methods. Hence, this study aims to correlate the pelvic and sacral morphometric with stature based on sex and ancestry among the Malaysian population.



**Fig. 1** Anatomical illustration of the pelvic girdle and pelvis (Kotarinos 2016)

## Methods

This was a retrospective cross-sectional study of the pelvic girdle. A total of 373 CT Scan Digital Imaging and Communications in Medicine (DICOM) folders from year 2010 to 2018 that stored in Picture Archiving and Communication Systems (PACS) were first retrieved retrospectively from living patient subjects of Radiology Department as well as postmortem subjects of National Institute of Forensic Medicine (NIFM) in Kuala Lumpur Hospital (HKL). These images were copied into encrypted external hard drive.

Postmortem subjects have been scanned by using 2-blocks CT for the whole body using a Toshiba

Aquilion 64 Postmortem Multi-slice CT scanner whilst living patient subjects have been selected from their diagnostic scans including the CT abdomen, CT pelvic and CT urography with 1.0 mm resolution in average. Subjects were carefully chosen based on sex subgroups (Male and Female) and ancestry subgroups (Malay, Chinese and Indian) for each decade subgroup from 10 to 79 years old as summarised in Table 1. The equal distribution of subjects could counterweight the variability of the confounders including sex, age and ancestry in this study.

The demographic data likewise sex, age, ancestry and height were traced from the Forensic Medicine Information System (FMIS) and Patient Appointment System (PAS). The height in centimetre (cm) for postmortem subjects were measured during the autopsy examination and retrieved from the postmortem reports. On the contrary, the heights for living patients were retrieved from the registration forms or confirmed by contacting the patients. Data collection for living stature is collected from various sources that are likely resulting in some error compared to cadaver stature but this will not significantly affect the results (Wilson et al. 2010). Cases were excluded if the history pointed the conditions that could have affected bone morphology of the pelvic girdle likewise fracture, burning, anomalies.

The pelvic and sacrum bones were first viewed and segmented likewise sex, age, ancestry and height by using software Mimic Research 17.0, available at the School of Dental Sciences, Universiti Sains Malaysia. Linear measurements including seven sacral parameters and eight pelvic measurements Tables 2, 3 and 4, Figs. 2 and 3 were taken in centimeter (cm) at 2 decimal points via the software 3D Builder (Garvin and Severa 2019). The measurements were taken twice to satisfy the intra-observer error analysis for all the subjects. Relative technical error of measurement (TEM) for

**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
20–29	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 sacrum parameters adopted from Kanika et al. (2011) and Shreekrishna et al. (2013)

No	Parameter(s)	Description
P1S	Sacral basal width	Maximum transverse midpoint distance of the superior surface of sacrum that comprising of the two alae
P2S	Transverse diameter S1 body	Maximum transverse midpoint diameter of the articular surface of the body of first sacral vertebra (S1)
P3S	Anteroposterior (A-P) diameter S1 body	Antero-posterior distance from the midpoint of sacral promontory up to the midpoint on the posterior border of S1 body
P4S	Average ala width	Maximum straight distance of the sacral ala from the right transverse diameter of the S1 body
P5S	Sacral height	The midpoint of the sacral promontory to the middle of antero-inferior border of the fifth sacral vertebra
P6S	Average auricular surface length	Maximum distance of the superior-inferior inner border of auricular surface on lateral aspect of sacrum
P7S	Average ala A-P length	Antero-posterior distance from the lateral posterior most point up to lateral anterior most point on the superior border of the ala

**Table 3** Definition and description of sacrum indexes adopted from Kanika et al. (2011) and Shreekrishna et al. (2013)

No	Index(es)	Description	Formula
I1S	Sacral index	Ratio of sacral basal width to sacral height (sacral mid-ventral straight length) (%)	$\frac{P1}{P5}$
I2S	Corporobasal index	Ratio of transverse diameter of S1 body (corpus width) to sacral basal width of S1 (%)	$\frac{P2}{P1}$
I3S	S1 body index	Ratio of anteroposterior (A-P) diameter to transverse diameter of S1 body (%)	$\frac{P3}{P2}$
I4S	Alar base-wing index	Ratio of average bilateral ala width to transverse diameter of S1 body (%)	$\frac{P4}{P2}$
I5S	Auricular index	Ratio of average bilateral auricular surface length to sacral basal width (%)	$\frac{P6}{P1}$
I6S	Alar diagonal index	Ratio of average bilateral ala width to average bilateral ala anteroposterior (A-P) length (%)	$\frac{P4}{P7}$

**Table 4** Definition and description of pelvic girdle parameters modified based on Lia et al. (2013)

No	Parameter(s)	Description
P1P	Ilium transverse length	Transverse diameter width of two apex of the antero-superior right and left iliac spine
P2P	Pubic inlet transverse diameter	Maximum central distance of the widest margins of the pubic inlet
P3P	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
P4P	Average pubic height	Distance between the most superior and most inferior point on the inferior edge of the medial aspect of the pubic symphysis
P5P	Average ilium breadth	Distance between apex of the postero-superior iliac spine and apex of the antero-superior iliac spine
P6P	Average ilium height	Distance between the most superior point of the iliac crest and the farthest point of ischial curve
P7P	Average acetabulum width	Maximum diameter of the points on the acetabulum margin corresponding to where ilium and ilio-pubic ramus meet
P8P	Average acetabulum height	Maximum diameter of the most inferior points of the anterior end of the lunate surface of the acetabulum

each parameter, which was acceptable if less than 5%, was calculated using Eqs. 1 and 2 (Perini et al. 2005). The calculation was shown in the equations below:

$$\text{Absolute TEM} = \sqrt{\frac{\sum d_i^2}{2n}} \tag{1}$$

where  $\sum d^2$  = summation of deviations raised to the second power,  $n$  = number of subjects measures,  $i$  = index of the case having values 1, 2, ...,  $n$

$$\text{Relative TEM} = \frac{\text{TEM}}{\text{VAV}} \times 100 \tag{2}$$

where TEM = absolute TEM from Eq. 1 expressed in %, VAV = average value of the parameters and indexes.

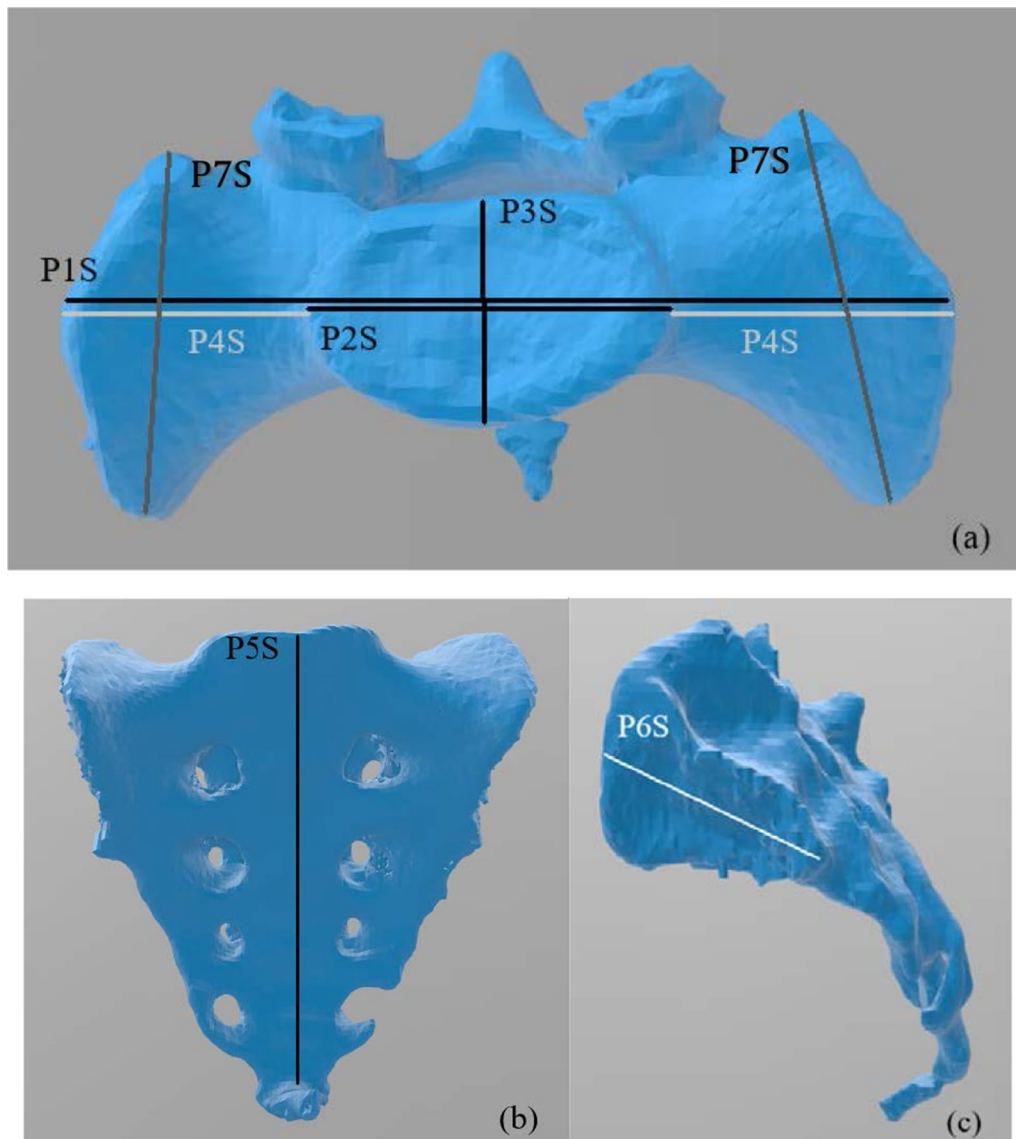
Extreme outliers had been removed from this study in order to eliminate the limitation of the analysis. The Kolmogorov–Smirnov test ( $N > 100$ ) was first conducted to determine normality at  $p > 0.05$  of all the parameters. Correlation analyses were performed by using Statistical Package for the Social Sciences (SPSS) version 24 to determine the relationship of pelvic and sacral morphometrics with the stature of the subjects according to sex and ancestry. The regression analyses were then performed by using well-correlated

parameters and then regression coefficients were acknowledged for each generated formula.

Further validation analysis of the stature regression equations was conducted by using holdout 56 subjects equally in both sexes, i.e. 15% separated from the total subjects (Mahakkanukrauh et al. 2011). This meant that the remaining 85% of the total subjects were utilised to generate new regression formulae from this study and to be tested by using the above mentioned holdout subjects. Validation test on the holdout subjects were performed by estimating the stature for each individual and comparing it to their actual stature. Afterward, the mean absolute deviation (MAD) and mean squared error (MSE) were computed.

**Results**

The descriptive statistics for the stature and normality were assumed as shown in Table 5. The stature of the selected subjects were normally distributed based on the histogram as plotted in Fig. 4. This proves that the stature distribution were unbiased during subject selection and acceptable for statistical analysis. There was a total of eight pelvic parameters and seven sacral parameters measured in this study to generate six indexes of sacral morphometric analysis for biological profiling.



**Fig. 2** Inter-landmark distances and parameters shown on the sacrum at superior view (a), anterior view (b) and lateral view (c). Screenshots obtained from Microsoft 3D Builder software

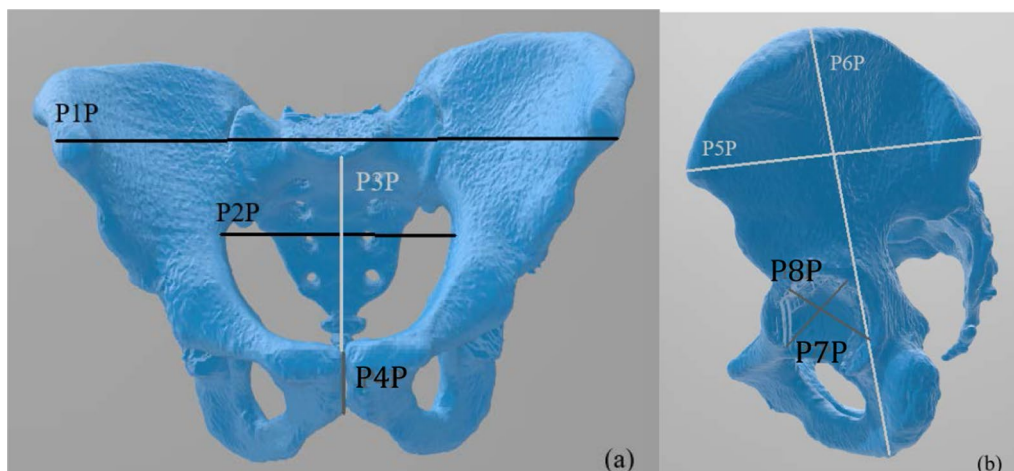
Descriptive statistics for the overall selected subjects had been listed in Table 6. Kolmogorov–Smirnov (K-S) test showed that normality was assumed at  $p > 0.05$  for all the parameters and indexes except alae A-P lengths (P7S), ilium transverse length and breadth (P1P & P5P), pubic inlet longitudinal diameter (P3P) and acetabulum dimensions (P7P & P8P). However, the boxplots of these parameters were normally distributed with the central spread of the parameter measurements.

From the results shown in Table 7, a significant difference between the right side and the left side of the pelvic bones and sacrum existed ( $p < 0.05$ ) except ilium

height and acetabulum width. These findings concurred with Boulay et al. (2006) 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 bones were required to be measured so as to consider the bilateral asymmetry of the pelvic girdle and the average of both sides shall be used for index calculations.

Kevin Norton's and Tim Old's methodology were applied by computing the technical error of measurements (TEM) as well as the coefficient of reliability in several previous studies (Goto and Nicholas 2007;





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

**Table 5** Descriptive statistics for age and stature of subjects selected

No	N	Minimum–Maximum	Mean ± SE	SD	K-S test p value
Stature	361	125.00–186.00	161.26 ± 0.48	9.20	0.200*

Unit in centimetre (cm)

\*  $p > 0.05$

Jamaiyah et al. 2010; Perini et al. 2005). In this study, duplicate readings for each of the parameters were measured by both Observer 1 and Observer 2 to compensate for the observer errors. There was no significant intra-observer and inter-observer error based on the paired sample t-test at  $p > 0.05$  with low relative TEM at below 5% and good reliability at above 0.8. Hence, these had assertively revealed that the morphometric data generated from the landmarking points chosen were precise and reliable for further analysis.

A total of 186 males and 175 females have been selected for the stature estimation based on the parameters and indexes as listed in Table 8 by using correlation and regression analysis. Sacral basal width (P1S), S1 body diameters (P2S & P3S), sacral height (P5S), alae A-P lengths (P7S), S1 body index (I3S) and auricular index (I5S) had a relatively significant positive correlation with stature at  $R < 0.500$ . However, the sacral index (I1S) and alae diagonal index (I6S) had a relatively significant negative correlation with stature at  $R < -0.200$ . All these parameters were considered in combination for regression formula with higher  $R$ -values as listed in Table 9.

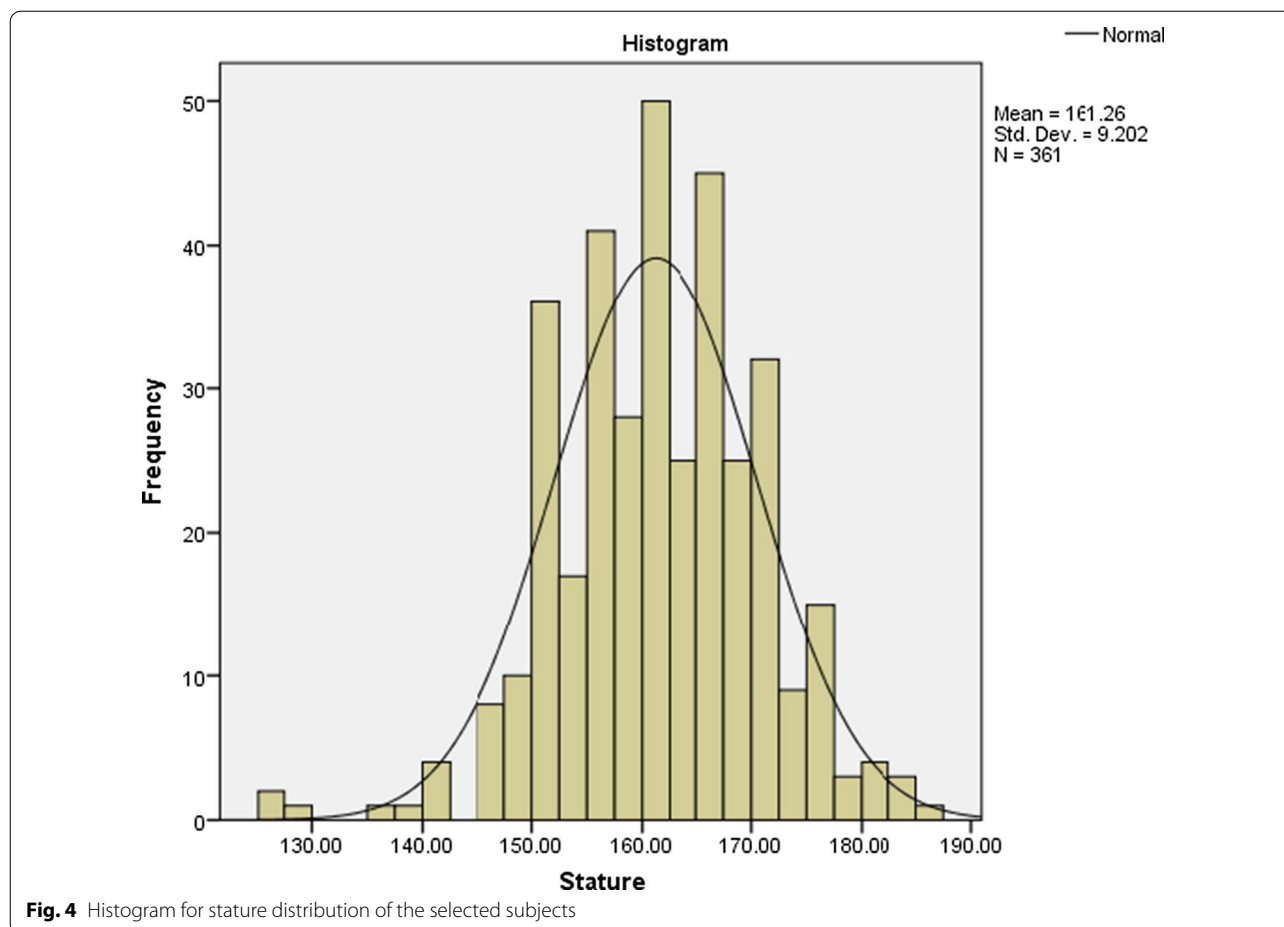
**Table 6** Descriptive statistics for parameters and indexes of pelvic and sacral morphometric

No	N	Minimum–Maximum	Mean ± SE	SD	K-S test p value
P1S	363	9.64–12.59	11.01 ± 0.03	0.58	0.061*
P2S	373	2.83–7.14	4.76 ± 0.03	0.67	0.200*
P3S	367	1.99–3.93	3.06 ± 0.02	0.32	0.170*
P4S	373	1.59–4.39	3.11 ± 0.02	0.37	0.200*
P5S	373	6.59–12.59	10.14 ± 0.05	0.99	0.200*
P6S	373	4.00–7.42	5.46 ± 0.03	0.58	0.060*
P7S	365	3.87–6.52	5.19 ± 0.03	0.52	0.024
I1S	359	84.66–137.50	108.64 ± 0.51	9.69	0.077*
I2S	363	25.84–59.95	43.45 ± 0.31	5.85	0.172*
I3S	365	43.64–86.85	64.55 ± 0.34	6.50	0.200*
I4S	367	33.89–112.50	66.44 ± 0.72	13.88	0.069*
I5S	363	35.34–65.96	49.95 ± 0.28	5.37	0.200*
I6S	358	42.27–85.65	59.87 ± 0.44	8.30	0.184*
P1P	360	15.29–26.97	22.79 ± 0.10	1.81	0.032
P2P	363	7.56–14.01	11.80 ± 0.05	0.96	0.064*
P3P	365	8.60–14.02	11.35 ± 0.06	1.07	0.042
P4P	371	1.82–4.59	3.11 ± 0.02	0.40	0.200*
P5P	370	10.18–17.22	14.58 ± 0.05	1.01	0.000
P6P	366	14.90–23.96	19.56 ± 0.07	1.38	0.200*
P7P	372	3.86–5.59	4.73 ± 0.02	0.37	0.001
P8P	372	3.89–5.75	4.77 ± 0.02	0.37	0.014

Unit in centimetre (cm)

\*  $p > 0.05$

In addition, auricular lengths (P6S) were the most useful stature estimator at positive correlation coefficient,  $R > 0.500$  at  $p < 0.001$ . Despite that, Zhan et al. (2018) had



reported relatively lower *R*-value for auricular length and A-P diameter of S1 body (P3S) but higher in sacral basal width (P1S) among Chinese population in China compared to the Malaysian population. Having said that, the *R*-value determined in this study for P2S and P5S had relatively lower *R*-value compared to the other studies

**Table 7** Paired sample statistics for symmetry analysis of pelvic and sacral morphometrics

No	N	Paired samples correlation	Correlation <i>p</i> value	t value	Paired samples <i>p</i> value
Pair 1: P4S	372	0.757	<0.001	2.045	0.042*
Pair 2: P6S	373	0.853	<0.001	-3.916	<0.001*
Pair 3: P7S	363	0.835	<0.001	2.196	0.029*
Pair 1: P3P	363	0.997	<0.001	-3.501	0.001*
Pair 2: P4P	371	0.955	<0.001	3.225	0.001*
Pair 3: P5P	364	0.936	<0.001	3.992	<0.001*
Pair 4: P6P	361	0.977	<0.001	-0.629	0.530
Pair 5: P7P	367	0.866	<0.001	0.376	0.707
Pair 6: P8P	367	0.876	<0.001	21.569	<0.001*

\* *p* < 0.05

(Lai et al. 2020). This had shown that the regression formula was totally dependent on the study population in their respective studies. The population-specific formula produced from this study should only be applied to the Malaysian population especially the three main ethnicities that were included in this study.

From the Table 10, ilium dimensions (P5P & P6P) and acetabulum dimensions (P7P & P8P) had a greater significant positive correlation with stature at *R* > 0.500 with even lower MAD and MSE compared to sacral morphometric within acceptable accuracy within SEE range. However, the pubic inlet dimensions (P2P & P3P) had no significant correlation with stature at *p* > 0.05. Subsequently, all these parameters with significant correlation were considered in combination for regression formula with higher *R*-values at *R* = 0.822 and smaller SEE, MAD and MSE as listed in Table 11.

Further validation analysis of the regression formulae was conducted by using holdout 28 males and 28 females. The remaining 85% of the total subjects were used to generate new regression formulae for each parameters and indexes. Estimated stature from the

**Table 8** Correlation and regression statistics for individual parameters and indexes of sacral morphometric against stature in validation analysis (Lai et al. 2020)

No	N	Regression formula	SEE	R value	R square	Mean Abs deviation	MSE	AWR (%)
P1S	297	131.903 + 2.711(P1S)	8.714	0.178*	0.032*	6.759	64.648	75.00
P2S	305	152.298 + 1.900(P2S)	9.305	0.143*	0.020*	6.550	62.834	76.79
P3S	299	126.885 + 11.304(P3S)	8.488	<b>0.393*</b>	<b>0.154*</b>	<b>4.988</b>	<b>40.279</b>	<b>87.50</b>
P4S	305	155.764 + 1.794(P4S)	9.373	-0.078	0.006	6.815	67.296	71.43
P4S'	304	153.663 + 2.500(P4S')	9.342	-0.109	0.012	6.920	68.399	71.43
P5S	305	125.401 + 3.531(P5S)	8.739	0.369*	0.136*	7.185	72.318	71.43
P6S	305	115.031 + 8.504(P6S)	7.973	<b>0.530*</b>	<b>0.281*</b>	<b>5.719</b>	<b>48.094</b>	<b>78.57</b>
P6S'	305	114.619 + 8.480(P6S')	7.813	<b>0.556*</b>	<b>0.309*</b>	<b>5.210</b>	<b>39.879</b>	<b>78.57</b>
P7S	296	141.601 + 3.813(P7S)	8.890	0.231*	0.054*	6.596	61.576	76.79
P7S'	296	142.825 + 3.612(P7S')	8.908	0.213*	0.045*	6.515	61.074	78.57
I1S	293	185.969 - 0.224(I1S)	8.656	-0.235*	0.055*	7.064	71.343	67.86
I2S	297	161.977 - 0.004(I2S)	8.855	-0.003	0.000	6.777	67.042	67.86
I3S	297	138.759 + 0.353(I3S)	8.955	<b>0.252*</b>	<b>0.064*</b>	<b>6.118</b>	<b>57.711</b>	<b>80.36</b>
I4S	299	162.858 - 0.022(I4S)	9.463	-0.033	0.001	6.669	65.328	75.00
I5S	297	127.861 + 0.679(I5S)	8.081	<b>0.409*</b>	<b>0.167*</b>	<b>5.823</b>	<b>50.828</b>	<b>82.14</b>
I6S	290	169.042 - 0.126(I6S)	9.095	-0.118*	0.014*	6.536	62.600	75.00

Unit in centimetre (cm)

SEE represents the standard error of estimation for the generated regression formula; R value represents the Pearson correlation coefficient; MSE represents mean squared error; AWR represents the accuracy percentage of estimated stature within SEE range compared to actual stature

Strong correlation results are in bold

\* p < 0.05

'Left side of the measurement.

**Table 9** Correlation and regression statistics for combination of parameters and indexes of sacral morphometric against stature in validation analysis

N	Regression formula	SEE	R Value	R Square	Adjusted R Square	Mean Abs Deviation	MSE	AWR (%)
279	122.360 - 0.059*I1S + 0.3773*I3S + 0.575*I5S - 0.116*I6S	7.901	0.486*	0.237*	0.225*	5.397	46.737	80.36
286	90.117 + 1.008*P1S - 5.061*P2S + 9.275*P3S + 0.718*P5S + 2.107*P6S + 4.726*P6S' + 3.153*P7S - 0.999*P7S'	7.138	0.615*	0.378*	0.360*	4.836	36.191	76.79
277	155.927 - 7.098*P1S - 6.073*P2S + 9.397*P3S + 3.262*P5S + 9.258*P6S + 12.337*P6S' + 1.586*P7S - 1.782*P7S' + 0.213*I1S + 0.016*I3S - 1.620*I5S - 0.168*I6S	7.112	0.633*	0.401*	0.374*	4.942	37.317	76.79

Unit in centimetre (cm)

SEE represents the standard error of estimation for the generated regression formula; R value represents the Pearson correlation coefficient; MSE represents mean squared error; AWR represents the accuracy percentage of estimated stature within SEE range compared to actual stature

\* p < 0.05

'Left side of the measurement

generated formulae was compared to the actual stature of the holdout subjects and the mean absolute deviation (MAD) were ranging from 4.988 to 7.185 cm in which lower than the standard of estimation error (SEE) of the respective regression formulae. Stature estimation based on anteroposterior diameter of S1 body (P3S) had achieved lowest MAD and mean squared error (MSE) with highest accuracy at 87.50% within SEE

range, followed by auricular length (P6S) though with slightly lower accuracy within SEE range.

**Discussion**

Generally, forensic anthropologists are more likely to be measuring dry bones rather than extracting measurements from CT data. There may also have some occasions whenever a mortuary receives an unknown case



**Table 10** Correlation and regression statistics for individual parameters of pelvic morphometric against stature

No	N	Regression formula	SEE	R Value	R square	Mean Abs deviation	MSE	AWR (%)
P1P	292	125.219 + 1.594(P1P)	8.701	0.321*	0.103*	6.946	70.730	71.43
P2P	295	155.594 + 0.512(P2P)	9.144	0.053	0.003	6.711	64.435	67.86
P3P	297	156.393 + 0.463(P3P)	9.127	0.056	0.003	6.597	62.706	75.00
P4P	303	129.591 + 10.187(P4P)	8.481	0.434*	0.188*	6.018	50.969	78.57
P5P	302	78.846 + 5.650(P5P)	7.480	0.606*	0.367*	5.647	49.003	76.79
P6P	300	57.536 + 5.303(P6P)	5.749	0.791*	0.625*	4.175	25.729	73.21
P7P	304	83.860 + 16.340(P7P)	7.089	0.658*	0.434*	4.209	28.309	82.14
P8P	304	82.142 + 16.546(P8P)	7.158	0.650*	0.423*	4.470	31.673	82.14

Unit in centimetre (cm)

SEE represents the standard error of estimation for the generated regression formula; R value represents the Pearson correlation coefficient; Sig. value represents the significant values of the regression ANOVA corresponding to the F value

\*  $p < 0.05$

**Table 11** Correlation and regression statistics for combination of pelvic morphometric against stature

N	Regression Formula	SEE	R Value	R Square	Adjusted R Square	Mean Abs Deviation	MSE	AWR (%)
289	$55.107 - 0.396*P1P - 1.737*P4P + 1.512*P5P + 4.403*P6P + 2.868*P7P - 0.184*P8P$	5.266	0.822	0.676	0.669	3.955	24.100	71.43

Unit in centimetre (cm)

SEE represents standard error of estimation for the generated regression formula; R value represents the Pearson correlation coefficient; Sig. value represents the significant values of the regression ANOVA corresponding to the F value

**Table 12** Comparison of estimated stature by using formulae from different studies in validation analysis

Transverse diameter S1 body (P2S)				Sacral height (P5S)		
Regression formula	Mean Abs deviation	Mean squared error	AWR (%)	Mean Abs deviation	Mean squared error	AWR (%)
Black African	6.607	68.988	69.64	9.741	140.346	41.07
White African	6.734	71.613	71.43	8.650	113.181	55.36
Japanese	–	–	–	50.868	2652.699	0.00
Present study	6.550	62.834	76.79	7.185	72.318	71.43

Unit in centimetre (cm)

AWR represents the accuracy percentage of estimated stature within SEE range compared to actual stature

with extensive degree of decomposition whereby positive identification may not be performed through facial recognition or fingerprint detection as well as the tissue and bone cleaning may be time consuming. This may require CT data can be extracted for measurements and even apply the concept of virtual anthropology for biological profiling. Bone measurement by virtual method was highly accurate and reliable as in conventional dry bone measurement method Normaizatul et al. (2019).

The asymmetry of the pelvis is mainly due to Krishan et al. (2010) concludes that there is a higher possibility of obtaining erroneous results while estimating stature from those body dimensions which show statistically

significant bilateral asymmetry when formula developed from one side is used on the other side. Future application that using the regression formulae generated from this study has to follow the similar methodology. This was consistent with Kurki (2017) whereby pelvic girdle was bilaterally asymmetry due to multiple selective factors including obstetrics, bipedal locomotion and environmental factors such as biomechanical loading effect.

As mentioned in Lai et al. (2020), the regression formulae for both transverse diameter of S1 body (P2S) and sacral height (P5S) that had been generated from previous studies on Africans by Pininski and Brits (2014) and Japanese by Torimitsu et al. (2017) were applied and

**Table 13** Correlation and regression statistics for combination of pelvic and sacral morphometric against stature according to sex

Sex(N)	Regression formula	SEE	R Value	R Square	Adjusted R Square	F Value	p value
M 179	$76.332 + 2.539*P1S + 1.885*P3S + 0.123*P4S + 0.670*P5S + 2.893*P6S + 2.533*P7S + 0.289*P8S$	6.551	0.522	0.273	0.243	9.154	<0.001
F 168	$105.491 - 2.121*P1S + 5.273*P3S + 8.390*P4S + 0.594*P5S + 3.205*P6S + 1.068*P7S + 0.054*P8S$	6.239	0.538	0.291	0.260	9.374	<0.001
M 181	$59.345 - 0.305*P1P + 0.979*P2P + 0.867*P3P - 1.874*P4P + 1.877*P5P + 3.419*P6P + 1.288*P7P - 0.886*P8P$	5.358	0.718	0.516	0.493	22.922	<0.001
F 167	$62.097 - 0.630*P1P + 0.629*P2P + 1.679*P3P + 2.307*P4P + 0.805*P5P + 2.437*P6P + 1.792*P7P + 1.900*P8P$	5.475	0.676	0.458	0.430	16.662	<0.001
M 178	$54.105 - 0.836*P1S + 0.193*P3S + 0.093*P4S - 0.202*P5S - 0.470*P6S + 0.980*P7S + 0.106*P8S - 0.209*P1P + 1.445*P2P + 1.052*P3P - 1.888*P4P + 1.645*P5P + 3.173*P6P + 1.582*P7P - 0.159*P8P$	5.412	0.726	0.527	0.483	12.040	<0.001
F 167	$58.928 - 0.273*P1S + 1.311*P3S + 1.481*P4S + 0.429*P5S - 0.958*P6S - 1.418*P7S + 0.113*P8S - 0.574*P1P + 1.142*P2P + 1.516*P3P + 3.092*P4P + 1.288*P5P + 2.047*P6P + 1.781*P7P + 2.586*P8P$	5.481	0.693	0.480	0.429	9.304	<0.001

Unit in centimetre (cm)

SEE represents standard error of estimation for the generated regression formula; R value represents the Pearson correlation coefficient; Sig. value represents the significant values of the regression ANOVA corresponding to the F value

tested by using the similar holdout subjects compared to the formula in this study. African formulae tended to overestimate based on both parameters (P2S & P5S) and Malaysia formulae generated from this study produced lower MAD and MSE with higher accuracy within SEE range as summarised in Table 12. Estimated stature based on Japanese formulae were totally out of the range compared to the actual stature. Hence, this had validated that the population-specific formula generated from this study should only be applied to the Malaysian population. Other than these two parameters, there was no any other similar pelvic morphometric that could be comparable with this study.

In overall comparison, pelvic morphometric (Table 11) was generally a better stature estimator compared to sacral morphometric (Table 9) that concurred with Giroux and Wescott (2008) and Torimitsu et al. (2015). This could be due to the locality of the bigger pelvic bones especially ilium height as part of the whole-body stature correlates better compared to sacral bones. In addition, Table 13 showed that the combination of pelvic parameters, sacral parameters and its indexes had contributed to a higher correlation regression coefficient compared to their respective individual estimation in both sexes.

Table 13 also showed that stature correlation and regression coefficient for pelvic morphometric were better in males compared to females which was supported by previous studies (Barbara and Philipp 2015; Pelin et al. 2005; Torimitsu et al. 2014, 2015). However, the generated formulae for overall combined sex as shown in Tables 9 and 11 could be better than formulae according to separate sex in stature estimation. The

recommendation of apply the formulae of combined sex for stature estimation in the cases of unknown bodies. The combination of pelvic parameters, sacral parameters and indexes had contributed to a higher correlation regression coefficient.

## Conclusions

The auricular lengths (P6S), ilium dimensions (P5P & P6P) and acetabulum dimensions (P7P & P8P) were the most useful stature estimator at  $R > 0.5$ . Regression formula was totally dependent on the study population in their respective studies for each individual parameters and indexes being applied. Combination of pelvic parameters, sacral parameters and its indexes had contributed to a higher correlation regression coefficient and smaller standard error of estimation compared to their respective individual estimation. In overall comparison, pelvic morphometric was generally a better stature estimator compared to sacral morphometric. The population-specific formula generated from this study should only be applied within the Malaysian population including Malay, Chinese and Indian. To conclude, this population-specific study based on pelvic girdle among Malaysian helps to improve the existing references for Forensic Anthropologists and Forensic Radiologists to perform stature estimation especially when incomplete human remains are discovered. In the future, researchers of a similar area of interest are recommended to explore more on into other body parts to complement the whole-body stature estimation methods.

## Abbreviations

3D: Three dimensional; CT: Computed tomography; DICOM: Digital Imaging and Communications in Medicine; FMIS: Forensic Medicine Information System; HKL: Kuala Lumpur Hospital; MAD: Mean absolute deviation; MRI: Magnetic resonance imaging; MSE: Mean squared error; NIFM: National Institute of Forensic Medicine; PACS: Picture Archiving and Communication Systems; PAS: Patient Appointment System; SEE: Standard of estimation error; TEM: Technical error of measurement.

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## Authors' contributions

LPS contributed to the conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing of the original draft, writing of the review and editing, visualization, and project administration. MHMN contributed to the methodology, writing of the review and editing, validation, supervision and resources. NA contributed to the methodology, writing of the review and editing, supervision and resources. All authors read and approved the final manuscript.

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## Availability of data and materials

Date will not be shared for public access and password protected as kept by the principal investigators.

## Declarations

### Ethics approval and consent to participate

This research has obtained ethical approval with the reference number KKM.NIHSEC.P18-2350(7) and registered under National Medical Research Registry (NMRR-18-3132-44576), Ministry of Health, Malaysia. Consent to participate is not applicable since retrospective data acquired under ethics approval by the Medical Research Ethics Committee of Ministry of Health, Malaysia.

### Consent for publication

Not applicable.

### Competing interests

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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