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SHORT COMMUNICATION

Estimation of body height from spinal length measurements using post-mortem computed tomographic images

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Abstract

Introduction: Post-mortem computed tomography (PMCT) provides information that helps in the determination of the cause of death and corpse identification of disaster victims. One of the methods for corpse identification includes assessment of the body stature. There is a lack of post-mortem imaging studies that focus on the anthropometric assessment of corpses. Our aim was to identify the relationship between cadaveric spine length and autopsy length (AL) among and autopsy length (AL) among a Malaysian population and derive a regression formula for the estimation of corpse body height using PMCT. *Materials and Methods*: We retrospectively assessed 107 cadavers that had undergone conventional autopsy and PMCT. We made 5 measurements from the PMCT that included cervical length (CL), thoracic length (TL), lumbosacral length (LS), total column length of the spine, excluding the sacrum and coccyx (TCL), and ellipse line measurement of the whole spine, excluding the sacrum and coccyx (EL). We compared these anthropometric PMCT measurements with AL and correlated them using linear regression analysis. *Results*: The results showed a significant linear relationship existed between TL and LS with AL, which was higher in comparison with the other parameters than the rest of the spine parameters. The linear regression formula derived was: 48.163 + 2.458 (TL) + 2.246 (LS). *Conclusions:* The linear regression formula derived from PMCT spine length parameters particularly thoracic and lumbar spine gave a finer correlation with autopsy body length and can be used for accurate estimation of cadaveric height. To the best of our knowledge, this is the first ever linear regression formula for cadaveric height assessment using only post mortem CT spine length measurements.

Keywords: Cadaver, computed tomography, autopsy, regression analysis, body height

INTRODUCTION

In the past decade, post-mortem CT (PMCT) imaging has become a useful tool in forensic practice due to CT algorithm which can elegantly depict bone structure, and for structural measurement.[1] Body height estimation is one of the crucial factors in the identification of unknown individuals.[2] Particularly for disaster victims, their bodies can be incomplete, macerated or unrecognisable which makes the role of conventional autopsy limited.[3] Dental records may aid in disaster victims identification. Other methods include estimation of the cadaveric height for disaster victim identification (DVI). Estimation of body height is still one of the main keys in recognising unidentified cadaver.[4] In an emergency clinical setting, obtaining patients' height can be difficult and there could be circumstances when the height of the patient is not clear or when the patient's condition is too frail for conventional height assessment using the height scale. Further, assessment of body height can be obtained by using the conventional autopsy length (AL) measurement or mathematically by using regression equations (indirect method). However, this is limited, due

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to the necessity of having a complete skeleton, to sum up, measured lines from the skull to the foot.[5] Thus, this may not be possible in DVI, particularly in incomplete corpses that have lost limbs, burnt victims and bodies that are recovered after advanced putrefaction. Hence, arise the need for a method to assess cadaveric stature by utilising a single body organ using the linear proportional relationship with the body's anthropometric measurement. Furthermore, using PMCT modality can be very supportive because of the ease of performing osseous measurements of anybody part in 3-dimensional format.[6]

Previous studies have suggested that CT osseous length estimation, such as pelvic, femoral and ulnar length measurements for total body length estimation were possible.[7,8] Another study conducted among the Portuguese population utilised the metatarsal bones and a study conducted among the Spanish populace utilised the primary sternum bones for cadaveric height assessment.[9,10] PMCT measurement of bone length can provide a close congruence with the actual autopsy length.[11] However, there is a lack of alternative methods on bone measurement in the instance that the victims have lost their limbs, thus we propose using the spine as a reference due to the length of the spine is closely related to the body. Parameters can be utilised to decide the body stature of an individual and at that point. The PMCT estimation of the parameters as of now has an appraise of the tallness of the body of the spine.[12]

Findings from this study provides useful information to the clinicians, scientists, researchers, and more importantly to the expert's forensic scientists who may use the results in enhancing further security challenges in our society, especially among Malaysians, as well as providing information on the importance of post-mortem CT (PMCT) and its usefulness in accurately determining the length of the cadaveric body. In a time like this where there is a lot of mass disaster occurring frequently across the globe, the study will be used to estimate the body weight of incomplete corpses, there is a lack of data from the Asian population who have different body build and stature and may require a unique equation for improved cadaveric body height estimation. Although PM-CT diagnosis still cannot replace the traditional anatomy, it can be used as an important supplement to traditional anatomy in helping and screening cases that need to be dissected to improve work efficiency rate.[13] The aim of this study was to utilise PMCT spine measurements and develop a linear regression formula for the estimation of cadaveric height.

MATERIALS AND METHODS

Subject recruitment

We used retrospective data from the Institut Perubatan Forensik Negara (IPFN), Hospital Kuala Lumpur, Malaysia after receiving ethical approval and permission (UPM/TNCPI/RMC/1.4.18.2 (JKEUPM)) to carry out the research by the Universiti Putra Malaysia Human Ethics Committee and the management of hospital Kuala Lumpur. We assessed 107 PMCT cases (90 males, 17 females), and correlated with the conventional autopsy report.[14] The demographic characteristic of the subjects is shown in Table 1. Cadavers of diverse ethnic Asian groups accounting from Malays, Chinese, Indians, and other ethnic Asian minorities were included in this study. The majority of the corpses were Indian (29.9%), Malay (27.1%), then by others (26.2%) and lastly by Chinese (16.8%). The age range of the cadavers was between 22 years and 68 years old at the estimation time of death with a mean of 44.39±11.22 years. All of the cadavers underwent whole-body PMCT examination before the autopsy, from 2014 to 2017 at the Institut Perubatan Forensik Negara (IPFN) KL. The research was conducted as per our study protocol as depicted in the methodology flowchart (FIG. 1).

Selection criteria

Selection of the subjects was done based on defined eligibility criteria, and only those cadavers that made the criteria were enrolled in the study. These criteria are summed up into; those who are included (inclusion) and those who are not (exclusion). PMCT scans of Malaysian cadavers ranging from 22 to 68 years old and having a normal bone morphology were included in this study. However, PMCT images or scans with poor quality and those from non-Malaysian subjects were strictly excluded from the study.

Sampling frame

A complete list of cadavers whose body underwent PMCT scans in the Radiology Department of the Institut Perubatan Forensik Negara (IPFN) was taken from the Radiological Information System (RIS) through written permission prior to the start of the data collection.

TABLE 1: Distribution of the cadaveric body according to socio-demographic characteristics (n = 107)

Variable(s)	n	%
Ethnicity		
Malay	29	27.1
Chinese	18	16.8
Indian	32	29.9
Others	28	26.2
Total	107	100.0
Gender		
Male	90	84.1
Female	17	15.9
Total	107	100.0
Age group (years) *		
22-30	17	16.2
31-40	17	16.2
41-50	45	42.9
51-60	16	15.2
61-70	10	9.5

* 2 missing data

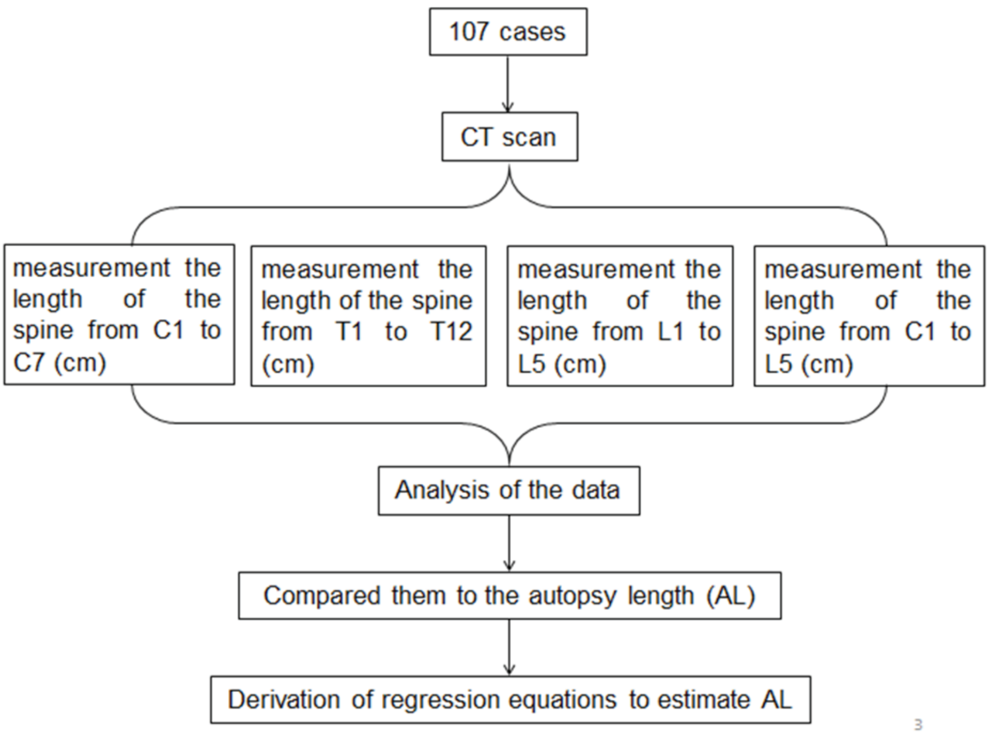

FIG. 1: Methodology flowchart.

Determination of sample size
Being that the data were collected retrospectively from the hospital record, the samples size hasn't been calculated. Samples were collected only based on the available record in the radiological department of the hospital. As such, we were able to identify a comprehensive list of 107 records of which their essential information was recorded and found at the time of collecting the data.

Pro-forma and processing of PMCT images
Pro-forma, a questionnaire-like form was designed and used to capture demographic information of the study subjects that includes age, gender, nationality, height, and date of death. Other parameters captured using this pro-forma were; length of each corpse from PMCT topogram length (TL), sternal length (SL) and thoracic column length (TCL), autopsy length (AL). All the images obtained from the Institut Perubatan Forensik Negara (IPFN) Kuala Lumpur were read and analysed using Syngo software at the Pusat Pengimejan Diagnostik Nuklear (PPDN), Universiti Putra Malaysia. Instruments used for these images are computed tomography scanning machine (CT scanner) and the images were measured using an image processing application (OsiriX) for viewing correct images. It is fully compliant with the DICOM standard for image communication and image file format converting.

Post-mortem CT imaging protocol
Post-mortem imaging was conducted on a 64-slice CT unit (Toshiba, Aquilion 64 CFX medical Systems Corporations, Tochigi, Japan). The whole body data acquisition done performed with the following technique: Supine with feet first, Direction: craniocaudal, kVp: 120, mAs: Auto set (Caredose mAs) FOV: 500(LL), Detector collimation: 1.0 x 32 raw, Pitch: 0.844/ standard, Focus: big, Reconstruction: slice thickness of 2.0 mm, interval of reconstruction of 1.6 mm (for soft tissue standard), scanning time of 120-150s. All subjects were scanned in a radiolucent body bag and in the supine position from head to toe with the hands by the side or on torso depending on the body rigor mortis. Multiplanar reconstructions (MPR) in a hard kernel (bone high resolution) and a soft kernel (soft tissue standard) done obtained.

Cadaveric autopsy measurement method
The cadaveric autopsy length was measured in a supine position on autopsy table from the vertex down to the foot.

Post-mortem CT spinal morphometry
The measurements of PMCT image parameters were conducted at the Centre for Diagnostic Nuclear Imaging, Universiti Putra Malaysia in a Leonardo Workstation (Siemens, Forchheim, Germany) by one observer. Anonymised images of the PMCT cases in DICOM format were uploaded into the system and viewed at the workstation. PMCT images of the whole spine were examined in multi-planar mode. The spinal length of each cadaver was measured on PMCT by drawing a line the sagittal view of the cervical spine length (CL) which was measured from the beginning of C1 to end of C7; thoracic spine length (TL) which was measured from T1 – T12; lumbar spine length (LS), which was measured from beginning of L1 to end of L5, the total whole spine column length (TCL) excluding the sacrum and coccyx and the ellipse length (EL) of the total whole spine excluding the sacrum and coccyx. We compared this to the autopsy length (AL).

Vertebral column measurement
Analysis of images was started by measuring the distance between the first cervical spine (C1) to the end of the last cervical spine (C7). The start point of measuring was the superior plate of the atlas C1 to the end point which is the inferior plate of the last cervical vertebrae C7, in a straight line as it showed in (FIG. 2A). Then followed by the measurement from the first thoracic vertebrae T1 to the end of the last thoracic spine T12, starting from the superior plate of the first thoracic vertebrae T1 to the inferior plate of the last thoracic vertebrae T12 which is the last point of the measurement in a straight line as shown in (FIG. 2B). Lumbar spine L1 to the end of the last spine of the lumbar L5 was measured from the superior plate of the first lumbar spine L1 to the inferior plate of the last lumbar spine which is L5 by a straight line as showed in (FIG. 2C). The vertebral column is measured as general from the superior plate of the first cervical spine atlas to the last lumbar spine L5, by a straight direct line as explained in (FIG. 2D). First cervical spine C1 to the last lumbar spine L5 was measured by Ellipse line from the length of the vertebral spine by an ellipse line following the curvatures in the vertebral spine, starting from the superior plate of the first cervical spine C1 to the inferior plate of the last lumbar spine L5 as it shows in (FIG. 2E).

Statistical analysis

All the images were obtained from the Institut Perubatan Forensik Negara (IPFN) Kuala Lumpur. The total number of the images was 107 CT images with an autopsy report for each case attached which contains all the related data about the cadaver such as weight, measured body height, and information such as age origin, gender, and date of death. Time for scanning every individual case was recorded from 2014 to 2017. The obtained images had been read and analysed at the Pusat Pengimejan Diagnostik Nuklear (PPDN), Universiti Putra, 43300 Seri Kembangan, Selangor, using Syngo software for measuring the involved variables. All spinal measurements was examined and checked by two professional radiologists after taking the best measure for all five spinal measurements.

Data was analysed by using Statistical Package for Social Sciences (SPSS) version 23. Pearson correlation coefficients (r) and linear regression analyses were used to determine the correlation between TL, SL, and TCL, with AL in order to derive a regression formula for estimation of body height using post-mortem Computed Tomography (PMCT). We correlated all the 5 different spinal measurement parameters with the autopsy length to formulate a linear regression equation for the cadaveric body length estimation. For the descriptive analysis of the study subject demographic data, the means and standard deviations were reported. For the

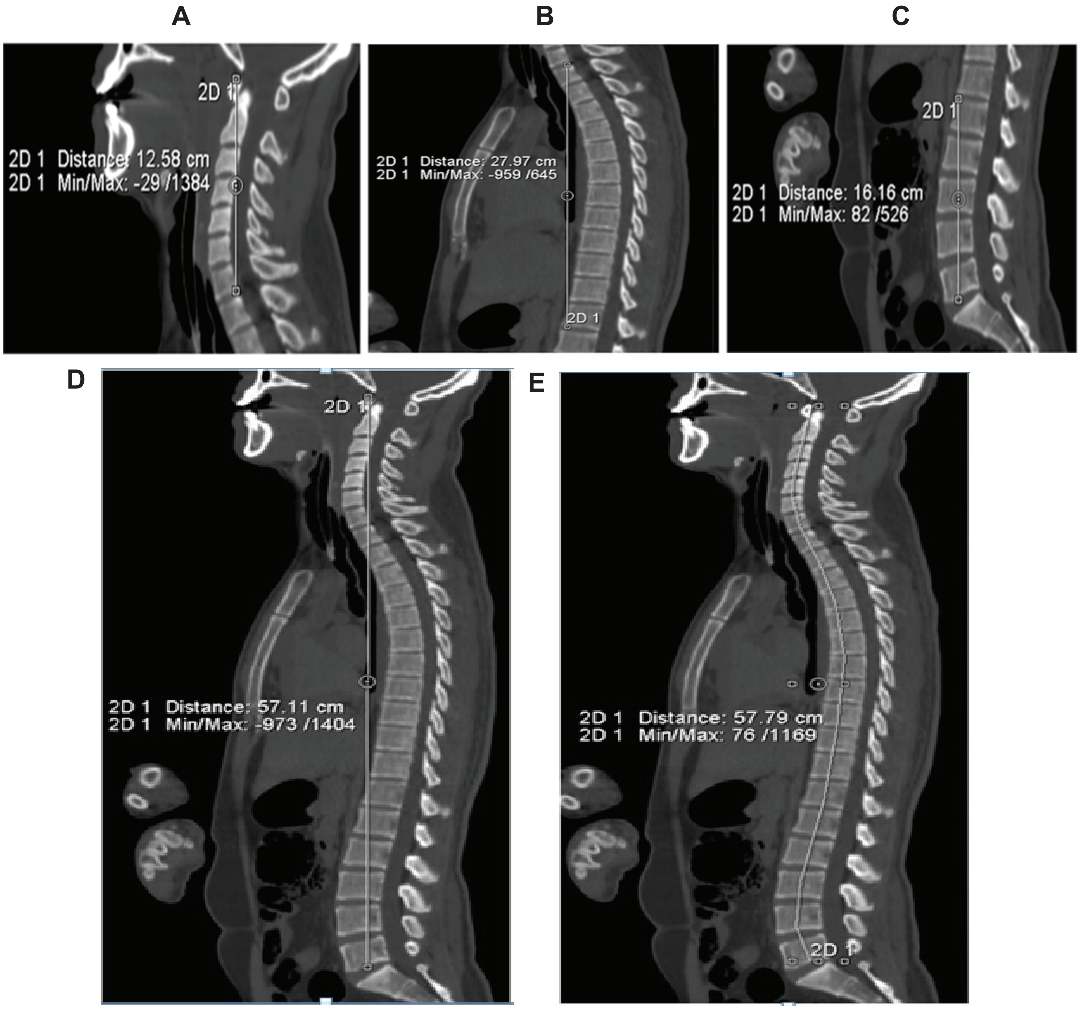

FIG. 2: **Vertebral column measurements** *a)* Cervical spine measuring from C1 – C7 by a straight line b) Thoracic spine measuring from T1 – T12 by a straight line, c) Lumbar spine measuring from L1 – L5 by a straight line, d) Total spine measuring from C1 – L5 by a straight line, e) ellipse measuring of the spine from C1 – L5.

PMCT spinal length parameter morphometric measurements, a test of normality of distribution was made and Pearson's correlation with the autopsy length was conducted. A p-value <0.05 was taken to be statistically significant. Linear regression analysis was performed to aid in deriving the formula for cadaveric height estimation.

RESULTS

Descriptive statistics associated with cadaveric spine and autopsy length across the study populations (Malay, Chinese, Indian and Others) are reported in Table 2. It was observed that the average autopsy length (AL) for all groups was 164.31±7.38 cm with a range between 147 to 186 cm. While the average spine lengths were CL: 12.07±0.83 for C1-C7, TL: 26.94±1.35 for T1 – T12, LS: 16.17±0.81 for L1–L5. TCL: 55.42±3.77 for a straight line from C1 to L5 and EL: 57.34±2.79 for C1-L5 Ellipse respectively. Moreover, the PMCT spine lengths and the autopsy length were not much difference between the subjects as seen in Table 2. To evaluate whether a difference existed between the ethnicity and the PMCT spine measurement parameters, one-way ANOVA was performed after ensuring that the data met the assumption of normal distribution. The assumption of homogeneity of variance was tested and was satisfied based on Levene's test as summarised in Table 3. The independent variables between groups using one way-ANOVA yielded no statistically significant difference among all the measurements. Thus, the null hypothesis of there is no difference between the means was retained. Hence, there is no difference in autopsy lengths and cadaveric spine among all the ethnic groups in Malaysia.

Linear regression analysis was performed to determine the relationship between C1-C7, T1-T12, L1-L5, C1-L5 Line, and C1-L5 Ellipse with AL. All the 5 spine parameter measurements mentioned above demonstrated a good linear relationship between spine length (C1-C7, T1-T12, L1-L5, C1-L5 Line, and C1-L5 Ellipse) and autopsy length (AL) with r = 0.683 and coefficient of determination r2 =0.467 which means 46.7% of the autopsy length is explained by the independent's variables (the spine length). Therefore, to get the autopsy length from the study subjects, a regression equation can be derived from the regression line (B) with the y-axis intercept at 48.163. A significant linear relationship exists between T1-T12, L1-L5 and autopsy length (AL) compared to the rest of the spinal parameters (C1-C7, C1-L5 Line, and C1-L5 Ellipse p>0.05 (Table 4). The linear regression formula AL = 48.163 + 2.458 (T1-T12) + 2.246 (L1-L5).

DISCUSSION

This study measured the length of the cadaveric spine on PMCT at various anatomical regions to find out the correlation between these measurements and the cadavers' actual body length. Then, we developed a linear regression formula for the estimation of cadaveric stature utilizing PMCT spinal length parameters. Further, a good linear relationship is provided between topogram length (TL), sternum length (SL) and thoracic column length (TCL) compared to the autopsy length (AL) of the corpse. These parameters could help biological anthropologists and forensic in furthering the research that will come up with something novel especially when these measurements are correlated with molecular markers found in the dead body. Equally, it can aide to improve in both research and post-mortem investigation. Although PM-CT is in forensic pathology highly specialised techniques for various application there are

TABLE 2: Descriptive statistics of the total cadaveric spine length and autopsy length

Variable	Mean ± SD (cm)	Range (cm)	
		Min	Max
AL	164.31±7.38	147.00	186.00
C1-C7	12.07±0.83	10.12	14.12
T1-T12	26.94±1.35	22.42	30.24
L1-L5	16.17±0.81	14.34	18.82
C1-L5 Line	55.42±3.77	26.51	61.47
C1-L5 Ellipse	57.34±2.79	49.87	65.54

TABLE 3: Comparison of morphometric measurements of cadaveric spine length among the study population

Variables	Ethnicity	Mean ± SD (cm)	*F* statistic (df)	*p*-value
AL	Malay	164.34±9.09	2.221(3, 103)	0.090
	Chinese	163.61±5.67		
	Indian	166.66±7.40		
	Others	161.89±5.53		
C1-C7	Malay	11.99±0.81	1.201(3, 103)	0.313
	Chinese	12.39±0.90		
	Indian	12.07±0.70		
	Others	11.95±0.94		
T1-T12	Malay	26.76±1.83	0.437(3, 103)	0.727
	Chinese	27.12±0.94		
	Indian	27.09±1.41		
	Others	26.87±0.86		
L1-L5	Malay	16.06±0.61	0.493(3, 103)	0.688
	Chinese	16.31±0.69		
	Indian	16.24±0.95		
	Others	16.12±0.89		
C1-L5 Line	Malay	55.10±2.84	0.479(3, 103)	0.698
	Chinese	54.79±7.32		
	Indian	55.98±2.70		
	Others	55.53±2.02		
C1-L5 Ellipse	Malay	56.84±2.40	1.541(3, 103)	0.208
	Chinese	58.52±3.02		
	Indian	57.40±2.98		
	Others	57.02±2.66		

broad application prospects, but there are certain limitations as a low resolution for soft tissue, need to combine nuclear magnetic resonance technology, need certain funds, technology, talent investment, and accuracy needs to be improved.

The highest race among the study population was the Indian by 29.9% from the total population, while the highest range of the age among the population was (41-50) years which was 45 corpses, while (31-40, and 22-30) years where 17 corpses, followed by (51-60) years 16 corpse, and finally (61-70) years only 10 cadavers. There is no statistically significant difference between the autopsy length and PMCT corpses' spinal length among all the ethnic groups in Malaysia. We used simple linear regression to find the accurate length of the corpse stature by measuring the spinal length in different methods, such as by regions, as general by a straight line, and by an ellipse, as depicted in Table 4. This explains the relationship between cadaveric spine length and autopsy length, whereby we found that the spine length by using regional measurement was the closest value that correlated positively with the autopsy length. A significant linear relationship exit between thoracic length and lumbar length with the autopsy length compared to the rest of the spine parameters.

A similar study using PMCT parameters but for lower limb bones instead was conducted in Japan and stated the benefits of PMCT in DVI. They determined the body stature, gender, and height of corpses by measuring the femur, tibia, and the first metatarsal bones in total bodies of the Japanese population cadavers (n= 259, 150 males, and 109 females). They assessed the bone mass, and length of bilateral femur, tibia, and fibula and the correlated values from the CT

TABLE 4: Relationship between cadaveric spine length and autopsy length

Variables	β (95% Cl)	t statistic	r	*p* value**
C1-C7	1.052 (-0.600, 2.704)	1.264	0.683	0.209
T1-T12	2.458 (1.249, 3.666)	4.035		0.001*
L1-L5	2.246 (0.431, 4.060)	2.455		0.016*
C1-L5 Line	0.100 (-0.259, 0.459)	0.552		0.582
C1-L5 Ellipse	-0.082 (-0.822, 0.658)	-0.219		0.827

**Simple linear regression

images. The results showed the correlation of the stature was equal to the femurs' length and mass volumes, with tibia, and fibula as well.[15] While the mass volume of the first metatarsal bone was higher.[15] Our findings are also in line with some previous studies using regression formulas to determine body mass index (BMI) and body height as well as measuring the long bone length and correlates it with the body height.[16,17]

There was a reported study conducted on living subjects to assess for body height using CT scan spinal parameter measurements. A study had used Cobb approach angle measurement that calculated the angle between L2, and T12 was conducted among 53 males and 47 females (age 64 ± 13 years) from the inferior endplate of L2 and the superior endplate of T12.[18] Their results stated that there is a strong correlation between the spine length and 318 the body height of the corpses and that has correlated with our findings. This is the first report to evaluate the feasibility of regional spinal length measurements for the estimation of cadaveric stature among Malaysian population. We believe that by using our proposed linear regression equation, we can accurately estimate corpse body height. In subjects with femoral fractures or loss of limbs, this spinal method of stature assessment may be an alternative way for non-invasively identifying disaster victims. Our study result shows the important role of PMCT spinal length measurements for the accurate estimation of cadaver height, particularly those with lost limbs or accidental deaths, to aid in disaster victim identification. The highlight of this study is the development of the regression formula for accurate estimation of an Asian population post mortem stature.

Muscle flaccidity allows joints to relax and influenced by the progressive increasing degree of rigor mortis during the first 6 hours of death. We have to consider the supine compared with standing position and the role of flattened intervertebral discs and vertebral bodies, kyphosis and other degenerative vertebrae diseases that could be represented in the sample as part of the limitation of this study. In addition, owing to the fact that small sample size was used in the study, and the imbalance in the gender with male corpses having high ratio than the female corpses and unidentified information regarding other ethnic groups used in the study, the study is limited and can be considered a preliminary report rather than a comprehensive study on Malaysian populations. This relatively small population sample is too small to draw a definitive conclusion as such further studies need to be carry out for age-stratified analysis of PMCT cadaveric length using large cohorts of samples.

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Authors' contribution: Subapriya Suppiah: Conceptual framework, Reference analysis, Manuscript preparation. Tawfiq Yousef Tawfiq Zyoud: Literature review, Reference analysis, preparing graphics, Manuscript writing. Ezamin Abdulrahim: Reference analysis, Data analysis, Funding. Abubakar Kabeer: Literature review, Reference analysis, preparing graphics. Rozi Mahmud: Funding, Consultancy/ overseeing the project, Manuscript. Saiful Nizam Abdulrahim: Study design, data analysis, Consultancy/ overseeing the project. Rosliza Abd Manaf: Data analysis, Reference analysis.

Conflict of interest: The authors declare they have no conflict of interest.

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