Estimation of adult stature based on the length of humerus, ulna and radius at a selected higher educational institution in Malaysia

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ABSTRACT

Background Estimation of stature has significant importance in the field of forensic medicine and anthropometry. It is crucial for personal identification, especially when the body has been destroyed or decomposed, or certain parts of unknown victims remain either in accidents or mass disasters. The stature of an individual conveys information regarding the age, sex, and race of a person. Upper limb bones can aid in estimating stature when lower limb bones are not available. Aim of the study The present study aimed to determine the relationship between stature and upper limb bones length among sex and races in the Malaysian population and to construct regression formulae for stature estimation using upper limb bones length among males and females in Malaysia. Methods A total of 210 subjects with an age span of 20-30 years were included in the study. The individual's height was measured standing erect, in anatomical position using a wall-mounted stature meter. The percutaneous lengths of the humerus, ulna, and radius were measured using an INSIZE vernier caliper. Results The mean height and percutaneous lengths of the upper limb bones of the males were statistically higher than the females ($p < 0.05$). There was a statistically significant difference ($p < 0.05$) in all the parameters between the three races. Strong positive correlations between stature and percutaneous length of humerus, ulna and radius were observed in both sexes that were statistically significant ($p < 0.001$). Regression equations for stature estimation were developed using the upper limb bones length for both males and females. The multiple regression equations were more accurate in predicting stature as they showed a smaller standard error of estimate (SEE) than simple regression equations. Conclusions The percutaneous length of humerus, ulna, and radius provides an accurate and reliable means of estimating the stature of an individual. The regression formulae derived in this study will be helpful to anatomists, anthropologists, archaeologists, and forensic scientists. The findings of this study can be used as a baseline for future Malaysian studies

KEYWORDS: Stature estimation, Anthropometry, Humerus, Ulna, Radius, Malaysian.

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INTRODUCTION

Stature is the natural height of an individual in an upright position. It is the distance measured from the bottom of the feet to the crown of the head (Durga Sukumar, 2017; Lemtur et al., 2017; Pal & Datta, 2014) and is greatly influenced by health, nutrition, genetic factors, growth and development in infancy, childhood, and adolescence. It is sexually dimorphous and statistically more or less normally distributed (Pal et al., 2019; Thummar et al., 2011) and is considered one of the significant anthropometric parameters for personal identification to anatomists, anthropologists, obstetricians, and in medicolegal practice (Bhavna & Nath, 2008; Numan et al., 2013). Stature estimation plays a crucial role in establishing the individuality of an unknown dead body or any mutilated part of the body in events such as murders, accidents, or natural disasters like earthquakes, tsunamis, floods, train crashes, plane crashes, or terrorist attacks by forensic and medicolegal experts (Lemtur et al., 2017; Siva Kumar et al., 2020). Evidence showed the measurements of limbs relative to stature exhibit constant ratios and these ratios are linked to age, sex and race (Thummar et al., 2011). The study in stature estimation could contribute to the statistical database for anthropometrical measurements in future studies (Mokhtari et al., 2021; Thummar et al., 2011). Because stature estimation from long bones cannot be measured directly, particularly in individuals who are debilitated, bedridden, or may have problems with the vertebral column or limbs, percutaneous measurements of long bones among the living have been adopted to formulate regression formulae for stature estimation (Armah et al., 2018; Mondal et al., 2009). Another reason is difficulty in getting dry bones for research studies (Mohd Nor, 2018) and unavailability of enough samples due to cultural, religious issue in Malaysian context, which may hamper such bone donation practice (Ismail et al., 2019). The aim of this study is generally to determine the relationship between stature and upper limb bones length in the Malaysian population, and specifically to examine the differences between stature and upper limb bones length (humerus, ulna and radius) by gender (male and female), and ethnic groups (Malay, Chinese and Indian) in Malaysia population. And subsequently to derive and construct regression formulae for stature estimation using upper limb bones length (humerus, ulna and radius) among males and females in Malaysia population.

METHODS

Study design

This study is a cross-sectional study and was conducted at AIMST University, Kedah, Malaysia. The research protocol was approved by AIMST University Human Ethics Committee (AUHEC) with reference number AUHEC/FOM/2022/01 before the implementation of the study. Informed consents were taken from all selected subjects among university student population from various faculties, regardless of their study years. The research involved human subjects was performed in accordance with Declaration of Helsinki and complied with the guidelines of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (Cuschieri, 2019).

Participants

A total of 216 were recruited in this study. Subjects' heights and the percutaneous lengths of the humerus, ulna, and radius on both the left and right sides were measured with a stature meter and vernier calipers, respectively. The materials used include INSIZE vernier caliper 1214-500 (0-500 mm), wall-mounted stature meter 200 cm, skin marker pen, surgical face mask, face shield, alcohol hand sanitizer, Dettol disinfectant spray, tables and chairs. Subjects were required to fill out a bilingual data collecting sheet with their personal information, which included their name, age, gender, and race.The researcher filled out the subjects' anthropometric measurements, consisting of their height, percutaneous length of the humerus, ulna, and radius on both sides.

Eligibility selection criteria

Inclusion criteria of the study were registered students in AIMST University, of Malaysian citizen. Age between 20-30 years old were selected as this age group is within an age range in which height remains more or less constant. Because a steady reduction in height is known to occur with age, thus elder subjects were not studied (Krishna Prasad et al., 2016). Besides, ossification of the upper limb is usually completed within 20-25 years of age; hence age group of 20-30 years old was chosen (Paul et al., 2020; Thummar et al., 2011; Yadav et al., 2015). -Criteria for exclusion in the study were subjects' age above 30 years old, non-Malaysian citizen; subjects with past or present history of injury or fracture to upper limb or surgery of upper limbs; cases of any significant long-term disease such as osteoporosis, orthopaedic malformation, metabolic or developmental diseases affecting the upper limb bones, or may have hampered general and skeletal growth; lastly persons with any deformity or amputated upper limb.

Sample size

The sample size was determined using OpenEpi software, Version 3.01 (Dean et al., 2013). The estimated samples were calculated by the two mean differences (mean 30.98 and SD of 2.43 and mean 28.27 and SD of 1.92) (Borkar, 2014). The samples will be 90 in each group with the power of 100% and 95% confidence intervals. Total samples with inclusion of non-response rate of 20% in this study were 216. A total of 216 people were chosen to participate in this study. However, 6 subjects were omitted as they did not fulfill the inclusion criteria. As a result, 210 people (105 males and 105 females) participated in the study. To compare conveniently among Malay, Chinese and Indian populations in matched group, each ethnic group of 70 people was predetermined.

Sampling method

Two-staged sampling methods were utilized in this study. First, samples of a predetermined size were obtained from each group based on the probability proportional to the size (PPS) of each group. PPS sampling (under stratified random sampling) assures that the size of each group (male and female) is the same as the study population. Then, quota sampling method was used to select samples for each group (male/female- Malay/Chinese/Indian).

Data collection procedure

The research was conducted in the Anatomy Unit, Faculty of Medicine of AIMST) University in Kedah, Malaysia. This research was conducted from November 2021 until July 2022 for a duration of 8 months. Data collection was initiated after obtaining AIMST University Research & Human Ethics Committee approval. Participants were recruited within a 2-month period, from April 2022 till May 2022. Before the study began, all subjects were given a bilingual information sheet and a verbal briefing from the researcher to understand the overall concept of the current study. Subjects who agreed to participate in the study were required to fill out and sign a consent form. The anthropometric measurement procedures were performed on eligible subjects who meet the inclusion criteria. The measurements were recorded in a data collection sheet. All measurements were obtained in a well-lit room. The study area's space was divided into two stations. Station one is for briefing and registration, with subjects filling out consent forms and demographic information on the data collection sheet. Subjects' identity details were kept confidential. Station two is for the measurement of height and percutaneous length of the humerus, ulna and radius. To avoid any technical or inter-observer error and maintain reproducibility, the same observer took and recorded all measurements using the same equipment. All measurements were taken in centimetres and at a consistent period between 1 pm and 5 pm to eliminate diurnal variation. Each measurement was taken three times, and the average value was recorded for height estimation. All the data was carefully entered and saved in an application database. Each subject was instructed to sanitize their hands and wear a face mask throughout the measurement in order to reduce their exposure to Covid-19 infection. Following the completion of the measurements, all instruments were thoroughly cleaned.

Measurement of stature

A wall-mounted stature meter was used to measure the height. Subjects were requested to remove shoes, caps, or hair accessories that would interfere with the height measurements (Bonell et al., 2017). They were instructed to stand erect in anatomical position, with their bare feet flat on the platform and their heads oriented in Frankfurt's plane. The subject's weight was uniformly distributed on both feet, with feet parallel to each other and heels, buttocks, and back touching the wall (Pal et al., 2019; Shakya et al., 2021). By bringing the horizontal sliding bar to the vertex, the length from vertex to heel was measured and recorded in centimetres to the nearest one decimal place (Paul et al., 2020).

Measurement of the length of humerus
The percutaneous humerus length was measured by having the subject flexs the elbow joint while standing. The flexor surfaces of the arm and forearm formed a 90-degree angle. The lateral epicondyle was palpated and marked with a skin marker pen on the lateral aspect of the elbow (Chandragirish et al., 2021). The acromion point was traced and marked by sliding the finger along the clavicle's lateral end (Armah et al., 2018). The INSIZE vernier caliper was used to measure the distance between two points, and the humerus length on both sides was measured. Because the acromion point lies 2 to 5 mm above the humeral head, the measured length was reduced by 2 mm. The measurement was taken in centimetres and recorded to the nearest one decimal place (Borkar, 2014; Chandragirish et al., 2021).

Measurement of the length of ulna
Before the measurement, subject was requested to bare his/her forearms and remove any jewellery, wristbands, or watches (Mokhtari et al., 2021). He/she was instructed to sit with elbow flexed at 90° and place palm over the opposite shoulder (Durga Sukumar, 2017; Lemtur et al., 2017). This will make both the tip of the olecranon process and the tip of the ulnar styloid process prominent (Paul et al., 2020). The two points are then marked with a skin marker pen, and the percutaneous ulna length is measured as the distance between the two points with an INSIZE vernier caliper. Ulna length was measured independently on the right and left sides, and the data was recorded in centimetres to the nearest decimal place (Chandra Sekar, 2021; Krishna Prasad et al., 2016; Prasad Sah et al., 2018).

Measurement of the length of radius
Subject was asked to bare his/her forearms and remove any jewellery, bracelets, or watches before the measurement (Mokhtari et al., 2021). Next, he/she was requested to sit, and the head of the radius was palpated in the extended elbow, the dimple lateral to the olecranon process of the humerus, and by moving the forearm in pronation and supination (Datta, 2009). The radial styloid process was palpated at the lateral aspect of the wrist joint in the supinated forearm by tracing down the lower lateral border of the radius (Datta, 2009; Pal & Datta, 2014). The radial head and tip of the radial styloid process were both marked using a skin marker pen. The percutaneous radius length was then measured using an INSIZE vernier caliper as the distance between the most prominent and palpable section of the radial head and the tip of the styloid process (Kumaran et al., 2014; Pal et al., 2019). The lengths of the left and right radius bones were measured individually, in cm, and recorded to the nearest decimal place.

Statistical Analysis
The data obtained were checked for missing data and then computed and tabulated in Microsoft Excel. All the data were statistically analyzed using SPSS version 26.0 (Armonk, NY: IBM Corp, 2019). The Shapiro-Wilk test was used to determine if the data sets showed a normal distribution. Data were summarized using descriptive statistics such as mean, standard deviation, and range. Independent samples t-test was utilized to compare mean differences in height and percutaneous lengths of the humerus, ulna and radius in males and females.

In contrast, One-way Analysis of Variance (ANOVA) (post-hoc) compared height and percutaneous lengths of the humerus, ulna and radius between different ethnic groups. Pearson's correlation coefficient was applied to evaluate the association of upper limb bones length with the individual's height. Linear regression analysis was employed to examine the extent to which upper limb bones length can reliably predict body height. Paired t-test was used to compare the mean differences between the estimated and true stature. A p-value less than 0.05 was considered statistically significant.

RESULTS

The percentage of males and females were 50% (n= 105) and 50% (n= 105) respectively. Both the males (n= 105) and females (n= 105) were subcategorized into three different race groups, which are Malay (n= 35), Chinese (n= 35), and Indian (n= 35). The percentage of each race group is 33.3% in this study. The mean age of the participants was 21.50±1.64 (Table 1). The Shapiro-Wilk test showed that the data (n= 210) were normally distributed.

Table 1 Demographic characteristics of study samples (n=210)

	Mean (SD)	Frequency	Percentage (%)
Gender			
Male		105	50
Female		105	50
Race			

Malay		70	33.3
Chinese		70	33.3
Indian		70	33.3
Age	21.50 (1.64)		

Note: SD: Standard deviation

Stature and Upper Limb Bones Length between Sexes

Descriptive statistics of stature and upper limb bones between males and females were calculated. The independent-samples t-test compared the mean values of stature and upper limb bones length between males and females irrespective of race, tabulated in Table 2. The mean height of the males was 171.24 ± 6.41 cm, ranging from 157.7 cm to 188 cm, while the mean height of the females was 157.78 ± 6.11 cm, ranging from 141.5 cm to 176.5 cm. Results showed that stature was significantly different between males and females ($p < 0.001$). Mean left and right percutaneous humeral lengths were 32.23 ± 1.74 cm and 32.30 ± 1.73 cm, respectively, for males, whilst females had 29.29 ± 1.59 cm and 29.39 ± 1.56 cm, respectively. Males had mean left and right ulnar lengths of 24.72 ± 1.49 cm and 24.79 ± 1.49 cm, respectively, whilst females had 22.20 ± 1.27 cm and 22.29 ± 1.26 cm, respectively. Mean percutaneous length of the left and right radius in males were 22.33 ± 1.40 cm and 22.43 ± 1.41 cm, respectively and that of females were 20.13 ± 1.20 cm and 20.24 ± 1.19 cm, respectively. There was a strong statistically significant difference ($p < 0.01$) in all the parameters between the two sexes.

Table 2 Results of stature and upper limb bones length between males and females

	Mean	SD	95% CI of the difference		t (df)	p
			Lower	Upper		
Height						
Male	171.24	6.41	11.76	15.17	15.570 (208)	0.000
Female	157.78	6.11				
Length of humerus left						
Male	32.23	1.74	2.48	3.38	12.773 (208)	0.000
Female	29.29	1.59				
Length of humerus right						
Male	32.30	1.73	2.46	3.36	12.817 (208)	0.000
Female	29.39	1.56				
Length of ulna left						
Male	24.72	1.49	2.15	2.91	13.224 (208)	0.000
Female	22.20	1.27				
Length of ulna right						
Male	24.79	1.49	2.13	2.88	13.151 (208)	0.000
Female	22.29	1.26				
Length of radius left						
Male	22.33	1.40	1.85	2.56	12.257 (208)	0.000
Female	20.13	1.20				
Length of radius right						
Male	22.43	1.41	1.84	2.55	12.202 (208)	0.000
Female	20.24	1.19				

Note: SD: Standard deviation; CI: Confidence interval; df: Degree of freedom; Significant when $p<0.001$; n=210 (Male:105; Female:105)

Stature and upper limb bones length between races

One-Way ANOVA (post-hoc) test compared the mean values of stature and percutaneous lengths of upper limb bones between races irrespective of genders, and it was tabulated in Table 3. The mean height, percutaneous length of humerus, ulna and radius of Indians are the highest compared to Malay and Chinese subjects. Chinese has a higher mean height and mean length of ulna and radius than Malay. However, Malay had a longer percutaneous humerus length than the Chinese. There was a statistically significant difference ($p < 0.05$) in all the parameters between the three races. Tukey's HSD (honestly significant difference) test was then done to perform multiple comparisons to find out which mean values were significantly different from each other. Results revealed that the mean height and the percutaneous length of humerus, ulna and radius were statistically different between Indian and Malay ($p < 0.05$). Besides, when compared between Indian and Chinese, the differences were statistically significant in all parameters except stature. Meanwhile, an insignificant difference in height and percutaneous length of humerus, ulna and radius was observed in Malay when compared to Chinese ($p > 0.05$).

Table 3 Results of stature and upper limb bones length between races

	Mean	SD	SEM	95% CI		F (df)	p
				Lower	Upper		

Height							
Malay	162.04	8.08	0.97	145.80	178.00	4.138 (2,207)	0.017
Chinese	165.21	9.39	1.12	146.50	182.00		
Indian	166.28	9.64	1.15	141.50	188.00		
Length of humerus left							
Malay	30.35	1.74	0.21	26.30	33.57	12.019 (2,207)	0.000
Chinese	30.16	2.26	0.27	25.47	33.70		
Indian	31.76	2.28	0.27	28.00	36.00		
Length of humerus right							
Malay	30.43	1.72	0.21	26.60	33.70	11.467 (2,207)	0.000
Chinese	30.29	2.23	0.27	25.40	33.83		
Indian	31.82	2.27	0.27	27.90	36.00		
Length of ulna left							
Malay	22.84	1.49	0.18	19.80	25.50	15.937 (2,207)	0.000
Chinese	23.13	1.84	0.22	19.07	27.80		
Indian	24.41	1.91	0.23	21.00	28.30		
Length of ulna right							
Malay	22.90	1.48	0.18	19.97	25.63	15.736 (2,207)	0.000
Chinese	23.25	1.84	0.22	19.20	27.90		
Indian	24.47	1.89	0.23	21.00	28.30		
Length of radius left							
Malay	20.55	1.40	0.17	17.73	23.00	15.851 (2,207)	0.000
Chinese	21.09	1.69	0.20	17.37	25.63		
Indian	22.05	1.69	0.20	19.03	25.30		
Length of radius right							
Malay	20.64	1.39	0.17	17.87	23.30	15.500 (2,207)	0.000
Chinese	21.23	1.71	0.20	17.47	25.63		
Indian	22.14	1.68	0.20	18.80	25.30		

Note: SD: Standard deviation; SEM: Standard error of mean; CI: Confidence interval; n=210 (Malay:70, Chinese:70; Indian:70)

Stature and upper limb bones length between males and females by races

Descriptive statistics of stature and upper limb bones between males and females by races were calculated. The mean values of stature and percutaneous length of upper limb bones in both sexes of the Malay, Chinese and Indian are compared and shown in Tables 4. The average values in males for all three ethnic groups were higher than their female counterparts. The stature was significantly larger in males compared to the females ($p < 0.05$). In addition, the percutaneous lengths of humerus, ulna and radius were significantly greater in males than females ($p < 0.05$) in Malay, Chinese and Indian.

Table 4 Comparison of stature and upper limb bones length between males and females by races

	Mean	SD	SEM	95% CI of the difference		t(df)	p
				Lower	Upper		
	Malay						
Height							
Male	168.43	4.86	0.82	10.42	15.13	10.841	0.000
Female	155.65	4.99	0.84			(68)	
Length of humerus left							
Male	31.45	1.31	0.22	1.56	2.85	6.818	0.000
Female	29.25	1.40	0.24			(68)	
Length of humerus right							
Male	31.53	1.31	0.22	1.57	2.84	6.925	0.000
Female	29.33	1.35	0.23			(67.954)	
Length of ulna left							
Male	23.96	0.93	0.15	1.78	2.71	9.616	0.000
Female	21.71	1.02	0.17			(68)	
Length of ulna right							
Male	24.02	0.94	0.16	1.77	2.70	9.657	0.000
Female	21.78	1.00	0.17			(68)	
Length of radius left							
Male	21.58	0.91	0.15	1.60	2.51	8.970	0.000
Female	19.53	1.00	0.17			(68)	
Length of radius right							
Male	21.67	0.91	0.15	1.60	2.49	9.088	0.000
Female	19.62	0.97	0.16			(68)	
	Chinese						

Height							
Male	172.01	6.33	1.07	10.51	16.68	8.787	0.000
Female	158.41	6.61	1.12			(67.868)	
Length of humerus left							
Male	31.84	1.51	0.26	2.63	4.08	9.314	0.000
Female	28.49	1.51	0.25			(68)	
Length of humerus right							
Male	31.93	1.52	0.26	2.56	4.00	9.076	0.000
Female	28.65	1.51	0.26			(68)	
Length of ulna left							
Male	24.44	1.40	0.24	2.00	3.23	8.456	0.000
Female	21.82	1.18	0.20			(68)	
Length of ulna right							
Male	24.54	1.41	0.24	1.95	3.20	8.217	0.000
Female	21.96	1.20	0.20			(68)	
Length of radius left							
Male	22.14	1.45	0.25	1.49	2.75	6.724	0.000
Female	20.03	1.17	0.20			(68)	
Length of radius right							
Male	22.28	1.48	0.25	1.45	2.74	6.488	0.000
Female	20.18	1.21	0.20			(68)	
	Indian						
Height							
Male	173.29	7.00	1.18	10.86	17.17	8.873	0.000
Female	159.27	6.19	1.05			(68)	
Length of humerus left							
Male	33.38	1.76	0.30	2.47	4.00	8.420	0.000
Female	30.14	1.43	0.24			(68)	
Length of humerus right							
Male	33.44	1.74	0.29	2.48	4.00	8.505	0.000
Female	30.20	1.44	0.24			(68)	
Length of ulna left							
Male	25.78	1.47	0.25	2.09	3.36	8.573	0.000
Female	23.05	1.18	0.20			(68)	
Length of ulna right							
Male	25.83	1.45	0.25	2.08	3.34	8.603	0.000
Female	23.12	1.17	0.20			(68)	
Length of radius left							
Male	23.28	1.25	0.21	1.90	3.00	8.857	0.000
Female	20.83	1.06	0.18			(68)	
Length of radius right							
Male	23.36	1.23	0.21	1.91	3.00	8.974	0.000
Female	20.91	1.04	0.18			(68)	

Note: SD: Standard deviation; SEM: Standard error of mean; CI: Confidence interval; df: Degree of freedom; n=210 (Malay male:35; Malay female:35; Chinese male:35; Chinese female:35; Indian male:35; Indian female:35).

Correlation coefficient between stature and upper limb bones length by gender

Pearson's correlation coefficient with bootstrapping was applied to evaluate the relationship between stature and percutaneous length of humerus, ulna and radius of males and females in Malaysia. The bootstrap can be used to assess the uncertainty of sample estimates. Besides, it is a computational method for simulating new samples to help evaluate how estimates from replicate experiments might be distributed and answer questions regarding precision and bias. (Kulesa et al., 2015). Mason and Mimmack (1992) justified the use of bootstrap confidence intervals in correlation coefficient as they argued that sample correlation is an unreliable measure of the true association. In males, the correlation coefficients (r) between stature and percutaneous length of the left and right humerus were moderately strong, which were 0.846 and 0.851, respectively. The r value between stature and length of the left and right ulna were 0.811 and 0.815, respectively. The stature also correlated well with the percutaneous length of the left and right radius ($r = 0.807$) (Table 5). In females, the correlation coefficient (r) between stature and percutaneous length of the left and right humerus were 0.754 and 0.769, respectively. The r value between stature and length of the left and right ulna were 0.791 and 0.803, respectively. The stature correlated best with the percutaneous length of the left and right radius in females, which $r = 0.806$ and $r = 0.812$, respectively (Table 5). The results (Table 5) showed strong positive correlations between stature and percutaneous length of humerus, ulna and radius in both sexes that were statistically significant ($p < 0.001$). This fact suggests that if the length of upper limb bones increases or decreases, the subject's height also increases or decreases and vice versa.

Table 5 Correlation coefficient between stature and upper limb bones length by gender

Male						
Height	LHL	LHR	LUL	LUR	LRL	LRR

	Mean	32.23	32.30	24.72	24.79	22.33	22.43
	SD	1.74	1.73	1.49	1.49	1.40	1.41
	[a]BCa95% CI Lower/Upper	31.91/ 32.54	31.98/ 32.62	24.45/ 25.01	24.52/ 25.08	22.08/ 22.59	22.17/ 22.69
	r	0.846	0.851	0.811	0.815	0.807	0.807
	p	0.000	0.000	0.000	0.000	0.000	0.000
	Female						
Height		LHL	LHR	LUL	LUR	LRL	LRR
	Mean	29.29	29.39	22.20	22.29	20.13	20.24
	SD	1.59	1.56	1.27	1.26	1.20	1.19
	[a]BCa95% CI Lower/Upper	29.00/ 29.60	29.10/ 29.70	21.98/ 22.44	22.06/ 22.54	19.89/ 20.37	20.01/ 20.48
	r	0.754	0.769	0.791	0.803	0.806	0.812
	p	0.000	0.000	0.000	0.000	0.000	0.000

Note: SD: Standard deviation; BCa: Bias-corrected and accelerated; [a]bootstrap results are based on 1000 bootstrap samples; CI: Confidence interval; LHR: Length of humerus left; LHR: Length of humerus right; LUL: Length of ulna left; LUR: Length of ulna right; LUR: Length of radius left; LRR: Length of radius right; n=210 (Male:105, Female:105).

Regression equations of stature estimation from upper limb bones length for males and females

The regression equations of stature estimation using the percutaneous length of humerus, ulna and radius for males and females were presented in Table 6. If only one bone was available for stature estimate, single linear regression equations were generated. Meanwhile, multiple regression equations were constructed for numerous bones to improve the accuracy (Ismail et al., 2018). Statistical analysis indicated that bilateral variation was insignificant for the measurements of upper limb bones length in both sexes ($P > 0.05$). Therefore, average values of both sides were used to develop regressions.

Stature was estimated by using a regression formula, $y = b + mx$ where,
y = estimated stature,
b = constant,
m = regression coefficient of an independent parameter,
x = percutaneous length of humerus/ulna/radius

In a regression line, the smaller the standard error of estimate (SEE), the more accurate the prediction was (Abu Bakar et al., 2017). In simple linear regressions, the lowest SEE was based on the percutaneous length of the humerus in males (SEE = 3.409) and the percutaneous length of the radius in females (SEE = 3.598). In multiple regressions, the lowest SEE was based on the combination of percutaneous length of both humerus and radius in both males (SEE = 3.164) and females (SEE = 3.210). Besides, the coefficient of determination (R-squared) shows how well the data fit the regression model (Figueiredo Filho et al., 2011). For example, an R^2 value of 0.762 indicated that there would be 76.2% of the variability observed in the stature when the percutaneous length of humerus, ulna and radius were used in combination in males. Meanwhile, in females, there will be 72.9% of the variability observed in the stature when the percutaneous length of humerus, ulna and radius were used in combination (R^2 = 0.729).

Table 6 Regression equations of stature estimation from upper limb bones length for males and females

	Regression	**SEE**	**R**	**R^2**	**F**	**p**
Male Stature	69.836 + 3.143 Hu	±3.409	0.849	0.720	265.106	0.000
Stature	84.515 + 3.503 U	±3.748	0.813	0.662	201.449	0.000
Stature	88.763 + 3.685 Ra	±3.802	0.807	0.652	192.935	0.000
Stature	84.701 +2.130 U + 1.510 Ra	±3.723	0.818	0.670	103.340	0.000
Stature	67.462 + 2.072 H + 1.491 U	±3.195	0.870	0.757	158.469	0.000
Stature	68.060 + 2.098 H + 1.585 Ra	±3.164	0.873	0.761	162.635	0.000
Stature	67.826 + 2.046 H + 0.391 U + 1.237 Ra	±3.176	0.873	0.762	107.673	0.000
Female Stature	70.786 + 2.965 Hu	±3.979	0.762	0.580	142.403	0.000
Stature	71.999 + 3.857 U	±3.698	0.798	0.638	181.173	0.000
Stature	73.928 + 4.155 Ra	±3.598	0.811	0.657	197.268	0.000
Stature	69.780 + 1.652 U + 2.539 Ra	±3.521	0.821	0.675	105.767	0.000
Stature	61.752 + 1.357 H + 2.527 U	±3.473	0.827	0.683	110.067	0.000
Stature	58.243 + 1.475 H + 2.787 Ra	±3.210	0.854	0.729	137.510	0.000
Stature	58.251 + 1.492 H - 0.074 U + 2.844 Ra	±3.226	0.854	0.729	90.786	0.000

Note: SEE: Standard error of the estimate; Hu: Humerus; U: Ulna; Ra: Radius; n=210 (Male:105, Female:105)

Comparison of true stature and estimated stature using simple and multiple regression equations for males and females

To validate the findings, the mean of actual stature was compared to the mean of estimated stature in both simple and multiple regressions using a paired t-test. The differences between the true stature and estimated stature for males and females were tabulated in Table 7 and Table 8, respectively. The results revealed that the estimated statures from all the upper limb bones measurements were not significantly different (p > 0.05) from the individuals' true statures. It indicated that estimated statures were reasonably close to the actual statures. As a result, this demonstrated that the regression equations developed could be used to estimate stature.

Table 7 Comparison of true stature and estimated stature using simple and multiple regression equations in males (n=105)

	Estimated stature in cm (mean ± SD)	Mean† difference	SEM	95% CI of the difference		t (df)	p
				Lower	Upper		
Humerus length	171.24 ± 5.44	-0.002	0.53	-0.66	0.65	-0.005 (104)	0.996
Ulna length	171.25 ± 5.22	-0,005	0.51	-0.73	0.72	-0.015 (104)	0.988
Radius length	171.25 ± 5.18	-0.010	0.51	-0.74	0.72	-0.027 (104)	0.979
Ulna and radius length	171.24 ± 5.25	0.002	0.51	-0.71	0.72	0.005 (104)	0.996
Humerus and ulna length	171.23 ± 5.58	0.011	0.54	-0.60	0.62	0.037 (104)	0.971
Humerus and radius length	171.23 ± 5.60	0.031	0.55	-0.60	0.62	0.035 (104)	0.972
Humerus, ulna and radius length	171.21 ± 5.60	0.031	0.55	-0.57	0.64	0.103 (104)	0.918

Note: SD: Standard deviation; SEM: Standard error of mean; CI: Confidence interval; df: Degree of freedom; †Mean difference between estimated stature and true stature (171.24 ± 6.41); Significant if p<0.05

Table 8 Comparison of true stature and estimated stature using simple and multiple regression equations in females (n=105)

	Estimated stature in cm (mean ± SD)	Mean† difference	SEM	95% CI of the difference		T (df)	p
				Lower	Upper		
Humerus length	157.79 ± 4.66	-0.010	0.45	-0.78	0.76	-0.027 (104)	0.979
Una length	157.78 ± 4.88	-0,006	0.48	-0.72	0.71	-0.016 (104)	0.987
Radius length	157.79 ± 4.96	-0.007	0.48	-0.70	0.69	-0.021 (104)	0.983
Ulna and radius length	157.77 ± 5.02	0.013	0.49	-0.66	0.69	0.037 (104)	0.971
Humerus and ulna length	157.78 ± 5.05	0.003	0.49	-0.77	0.67	0.010 (104)	0.992
Humerus and radius length	157.77 ± 5.22	0.006	0.51	-0.61	0.62	0.019 (104)	0.985
Humerus, ulna and radius length	157.78 ± 5.22	-0.006	0.51	-0.62	0.61	-0.018 (104)	0.986

Note: SD: Standard deviation; SEM: Standard error of mean; CI: Confidence interval; df: Degree of freedom; †Mean difference between estimated stature and true stature (157.78 ± 6.11); Significant if p<0.05

Table 9 Comparison of mean length of humerus of different populations

Author(s)	Study Population	Age group (years)	Mean Stature (cm)		Mean Humerus Length (cm)	
			Male	Female	Male	Female
Prateek et al. (2013)	North Indian	17-22	167.73 ± 6.72	153.1 ± 5.16	34.78 ± 1.93	28.0161 ± 1.29
Borkar (2014)	Western region of Maharashtra	20-30	173.8 ± 8.80	157.6 ± 7.98	L: 30.92 ± 2.44 R: 30.98 ± 2.43	L: 28.12 ± 1.93 R: 28.27 ± 1.92
Armah et al. (2018)	Ghanaians	18-43	171.36 ± 6.10	162.61 ± 4.92	L: 35.62 ± 2.16 R: 35.70 ± 2.30	L: 32.74 ± 2.86 R: 32.77 ± 2.89
Ismail et al. (2018)	Malaysian	23-47	168.24 ± 6.93	155.69 ± 5.78	30.66 ± 1.72	27.71 ± 1.74
Chandragirish et al. (2021)	South Indian	18-28	163.16 ± 4.55	156.83 ± 3.77	31.55 ± 1.56	30.15 ± 1.07
Present study	Malaysian	20-30	171.24 ± 6.41	157.78 ± 6.11	L: 32.23 ± 1.74 R: 32.30 ± 1.73	L: 29.29 ± 1.59 R: 29.39 ± 1.56

Table 10 Comparison of mean length of ulna of different populations

Author(s)	Study Population	Age group (years)	Mean Stature (cm)		Mean Ulna Length (cm)	
			Male	Female	Male	Female
Ilayperuma et al. (2010)	Sri Lankan	20-23	170.14 ± 5.22	157.55 ± 5.75	27.56 ± 1.30	25.11 ± 1.24
Thummar et al. (2011)	Gujarat	20-40	169.87	155.21	L: 28.39 R: 28.48	L: 25.54 R: 25.99
Yadav et al. (2015)	Nepalese	25-40	169.56 ± 4.56	157.45 ± 3.79	27.20 ± 1.18	23.67 ± 1.17
Bamne et al. (2015)	Maharashtrian	20-25	172.31 ± 6.28	158.84 ± 6.13	L: 27.75 ± 1.17 R: 27.90 ± 1.20	L: 25.32 ± 1.54 R: 25.41 ± 1.24
Anand & Nandyal (2016)	Gulbarga	21-25	172.13 ± 6.8	157.28 ± 5.8	L: 27.69 ± 1.2 R: 28.10 ± 1.2	L: 25.05 ± 1.2 R: 25.48 ± 1.2
Krishna Prasad et al. (2016)	Maharashtrian	18-28	172.93 ± 6.52	166.53 ± 3.57	L: 27.26 ± 1.35 R: 27.52 ± 1.33	L: 21.68 ± 0.87 R: 21.75 ± 0.92
Durga Sukumar (2017)	Andhra Pradesh	21-24	165.72 ± 3.95	160.58 ± 3.52	L: 29.78 ± 2.04 R: 29.84 ± 2.03	L: 26.63 ± 0.72 R: 26.70 ± 0.73
Lemtur et al. (2017)	Nagaland	19-35	168.12 ± 5.48	157.0 ± 5.4	L: 27.42 ± 1.24 R: 27.45 ± 1.21	L: 25.0 ± 1.29 R: 25.15 ± 1.29
Ismail et al. (2018)	Malaysian	23-47	168.24 ± 6.93	155.69 ± 5.78	29.28 ± 1.69	26.56 ± 1.79
Siva Kumar et al. (2020)	Chennai	18-22	168.02 ± 9.76	156.04 ± 6.21	L: 26.49 ± 2.85 R: 26.61 ± 2.92	L: 24.78 ± 2.58 R: 24.94 ± 2.64
Gul et al. (2020)	Multan	20-27	171.70 ± 8.05	157.30 ± 8.22	27.40 ± 2.13	24.70 ± 1.43
Paul et al. (2020)	West Bengal	20-50	164.20 ± 9.66	149.63 ± 7.38	L: 26.95 ± 1.42 R: 27.02 ± 1.44	L: 24.12 ± 1.62 R: 24.18 ± 1.62
Mokhtari et al. (2021)	Iranian	20-40	176.45 ± 11.9	161.29 ± 10.1	L: 29.03 ± 1.44 R: 29.05 ± 1.63	L: 27.78 ± 1.45 R: 27.74 ± 1.49
Sarma et al. (2022)	Khasi (North-Eastern India)	25-45	160.85 ± 6.34	149.56 ± 2.95	24.41 ± 1.10	22.58 ± 0.47
Present study	Malaysian	20-30	171.24 ± 6.41	157.78 ± 6.11	L: 24.72 ± 1.49 R: 24.79 ± 1.49	L: 22.20 ± 1.27 R: 22.29 ± 1.26

Table 11 Comparison of mean length of radius of different populations

Author(s)	Study Population	Age group (years)	Mean Stature (cm)		Mean Radius Length (cm)	
			Male	Female	Male	Female
Pal & Datta (2014)	Bengal	21-50	164.2 ± 7.50	-	L: 25.7 ± 1.34 R: 25.8 ± 1.34	-
Issa et al. (2016)	Egyptian cadavers	18-65	172.3 ± 11.4	158.5 ± 1.49	25.6 ± 1.41	25.3 ± 1.37

Ismail et al. (2018)	Malaysian	23-47	168.24 ± 6.93	155.69 ± 5.78	28.92 ± 1.69	26.03 ± 1.94
Pal et al. (2019)	Bengal	21-50	-	153.8 ± 6.79	-	L: 23.7 ± 1.39 R: 23.7 ± 1.36
Present study	Malaysian	20-30	171.24 ± 6.41	157.78 ± 6.11	L: 22.33 ± 1.40 R: 22.43 ± 1.41	L: 20.13 ± 1.20 R: 20.24 ± 1.19

Tables 9, 10, and 11 above compared the stature and mean lengths of the humerus, ulna, and radius of past studies to the current research. It was noted that the mean height and percutaneous measurements of humerus, ulna and radius of subjects within an age group varied in different populations for both male and female participants. In comparison with other populations, Malaysians were shown to have shorter upper limb bones in general when compared to other populations. These findings agreed with those of Singh et al. (2013), who reported that inter-population differences exist in both males and females. These variances may be attributable to geographical, racial and genetic factors, dietary patterns, lifestyles (urban or rural life), nutrition and physical stress (Armah et al., 2018; Krishna Prasad et al., 2016; Mokhtari et al., 2021; Singh et al., 2013). In addition, there may be differences in the nutrients obtained from food because of variations in staple foods and nutritional usage. Nutrients might play a crucial role in bone development (Armah et al., 2018; Prentice et al., 2006; Singh et al., 2013). In addition, environmental factors such as strenuous physical activity, viral infections, hormonal disorders, malnutrition, and poor living situations might prevent an individual from achieving the genetically determined adult height and have an impact on bone growth and development (Bogin & Varela-Silva, 2010; Mokhtari et al., 2021; Proia et al., 2021). When we compared the present study to the study conducted by Ismail et al. (2018), which also focused on the Malaysian population, we noticed that the humerus, ulna, and radius lengths differed. We obtained longer humerus lengths but shorter ulna and radius lengths than Ismail et al. (2018). The differences could be attributed to the methods and techniques used to measure the lengths of upper limb bones. Ismail et al. (2018) used radiography (X-ray) to take measurements, whereas we measured the lengths of upper limb bones percutaneously with a vernier caliper. When using the X-ray machine, there is a possibility of technical errors. Furthermore, it could be due to the smaller sample size in their study (n = 90), which reduced the representativeness of the population's diversity. Thus, more similar studies with an extended sample size on the Malaysian population should be conducted to validate the findings and compare the accuracy and utility of different methods for performing anthropometric measurements. Aside from that, Krishna Prasad et al. (2016) proposed that if the differences in mean height and bony length between populations were due to geographical, racial and genetic causes, we might reasonably assume that they will remain constant throughout time. However, if the predominant influence is discovered to be plastic, like dietary habits, lifestyles and physical stress, it was hypothesized that the anthropometric parameters would have to be assessed in the context of such influences on a regular basis to ensure their validity (Krishna Prasad et al., 2016). Nevertheless, it is worth remembering that a good sample size is essential in any research study in order to attain high validity and reliability in the results. With Malaysia's population growing to over thirty million people, a representative number of samples would be around 400 (Abu Bakar et al., 2017). This should be considered in future studies of stature estimation in the Malaysian population. Thus, it can be concluded that the percutaneous length of humerus, ulna and radius can be utilized to estimate stature.

DISCUSSION

The stature or height of an individual of either sex is a vital body dimension of interest in studies and investigations. It is usually related to studies of population's health and nutrition, growth and development of infants, children and adolescents, characterization of genetic disorders, sports and defense studies, ergonomics, evolution and comparative anatomy of living humans with primates and prehistoric ancestors (Banik et al., 2012; Thummar et al., 2011). In addition, stature estimation from partial skeletal remains is crucial in personal identification, forensic and medicolegal practice, and other biomedical sciences. It also provides important information for policymakers (Bhavna & Nath, 2008; Numan et al., 2013; Yadav et al., 2015). All human beings on the planet were members of the same species, Homo sapiens. No two people were exactly alike in all their measurable traits; even genetically identical twins (monozygotic) differed in some respects (Supare et al., 2015). Human stature has substantially increased during the past two centuries. Secular change was the term used to describe this shift across time. A number of epigenetic or environmental factors appeared to contribute to secular change (Langley & Jantz, 2020; Shook, 2020). Despite a general upward tendency in stature, research indicated that there were sporadic declines (Krishna Prasad et al., 2016). Negative changes appeared to occur during times of economic hardship, such as war and economic recession. During World War II, the decrease in stature was noted in Russia, Japan, and Germany. Secular change is more pronounced in men than women, with environmental factors suspected to be the primary cause of the differences. The environment was also shown to impact the sexes independently of each other and in unique ways (Krishna Prasad et al., 2016; Ryan & Bidmos, 2007). When the three races in Malaysia were compared, Indians were found to be taller and had a greater percutaneous length of the arm and forearm bones than Malays and Chinese. At the same time, the Chinese were taller and had longer ulna and radius than the Malays. The differences in stature and upper limb bones length between Indians and Malays were statistically significant. Except for stature, the differences between Indians and Chinese were statistically significant in all other parameters. However, there is no discernible difference between Chinese and Malay. According to Banik et al. (2012); Eveleth & Tanner (1990), there was an existence of differences in body proportions between ethnic groups. The findings of the present study agreed with the statement above. These differences could be caused by a complex interplay of physical activity, growth, climate, nutrition, disease, environmental, and genetic factors (Bogin et al., 2001; Navid et al., 2014; Numan et al., 2013; Vashisht et al., 2005). Moreover, Madden et al. (2012) discovered that there was significant racial diversity in the correlation of stature and ulnar length in White, Black, and Asian populations. The present study further highlights the racial variation in the mean lengths of humerus, ulna and radius of the Malaysian population. In the present research, the results revealed that the stature was significantly correlated with the percutaneous length of humerus, ulna and radius in both sexes ($p < 0.001$). The right humerus was the bone most correlated with stature in men ($r = 0.851$), whereas the right radius was the best bone to use in women ($r = 0.812$). We can observe from this present study and others that there has always been a strong positive correlation between stature and percutaneous lengths of the humerus, ulna, and radius in both males and females. It was assumed that as the length of the upper limb bones increased, so would the stature. As a result, the percutaneous measurements of upper limb bones could be utilized to estimate stature in both sexes, assisting in the identification of an individual from unknown human remains. The highest correlation coefficient will provide the highest reliability and accuracy in determining male and female stature. Furthermore, the current study demonstrated that there were no significant differences in anthropometric measurements between the right and left arm and forearm. In both males and females, the right humerus, ulna, and radius were numerically slightly longer than the left. Because the majority of the participants recruited in this study were right-handed, frequent use of the right hand may have resulted in an increase in cortical area in the brain and higher neural activation associated with the right arm. It will cause the right arm to be used more frequently than the left arm (Amunts et al., 2000; Armah et al., 2018). However, this difference was not statistically significant to influence the individuals' bilateral symmetry phenotypically. In earlier studies, researchers discovered that there were no statistical differences between different sides of the upper extremities (Armah et al., 2018; Ilayperuma et al., 2010; Ismail et al., 2018; Lemtur et al., 2017; Trotter & Gleser, 1952). Therefore, several studies utilized only the bone of one side to develop regressions (Ilayperuma et al., 2010; Ismail et al., 2018; Krishna Prasad et al., 2016; Lemtur et al., 2017). Some researchers used the average values of the right and left sides to formulate regressions (Gul et al., 2020; Hasegawa et al., 2009; Sarajlić et al., 2006; Yadav et al., 2015). In addition, studies demonstrated that bilateral asymmetry existed whereby the farmers typically had stronger hands on the dominant side because of routine extraneous exercise (Kanchan et al., 2008; Krishan et al., 2010; Krishan & Sidhu, 2008). Bilateral variations in upper limb bone dimensions were attributed to differences in mechanical stress and strain encountered by the bones during bone growth (Kanchan et al., 2008; Krishan et al., 2010; Nandi et al., 2018). Therefore, analyzing both sides of the upper limbs is feasible before deciding whether to construct regressions for a particular population using a single side or an average of both sides. Since there were no statistically significant differences in upper limb bone length between the right and left sides, average values of both sides were used to generate regression equations in this study.

CONCLUSIONS

Determining an individual's stature from unknown or fragmented bones remains is still a challenging task. Although numerous studies were carried out, formulas derived from a particular population do not fit worldwide because of the genetic, ethnic, dietary, climatic and other innumerable differences. In accordance with the findings of this study, it can be concluded that Malaysian males had statistically higher mean stature and percutaneous length of upper limb bones (humerus, ulna and radius) than females. There were statistically significant differences in all parameters between the three races (Malay, Chinese and Indian). A strong and significant positive correlation existed between stature and upper limb bones length ($P < 0.05$). Thus, this showed that humerus, ulna and radius lengths were trustworthy and reliable body parameters for predicting stature. The important aspect of this study was that the regression equations developed can be used as a reference to estimate the stature of the Malaysian population in the age group of 20-30. These formulae will be of practical use to anatomists, anthropologists, archaeologists and forensic scientists where the total stature of a subject can be calculated if the humerus, ulna and radius length are known. Moreover, the derived regression equations can aid in artificial limb centres for the construction of prostheses required in cases of amputations following gangrene, trauma, and frostbite. This study’s findings can be used as a baseline for future Malaysian studies. The study’s limitation was that the results of this investigation provided only the gender-specific regression equations for estimating stature from the lengths of humerus, ulna and radius among Malaysians. Due to concerns about insufficient sample size, race-specific regression equations were not formulated. As a result, future work on a larger population is recommended to assure that the sample is large enough to represent the entire Malaysian population and that valid race-specific regression equations can be constructed. In addition, it is advised that similar studies should be carried out on individuals of different age groups to determine the association between age-sex variation in stature and upper limb bones length. Moreover, it would be good to extend the study to include other upper extremity dimensions (such as arm span, hand length, hand width, finger length and wrist width) and lower extremity anthropometric measurements (such as lengths of femur, tibia and fibula and foot length) as well for comparison. These data could subsequently be utilized to estimate stature in cases when only parts of skeletal remains are discovered.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was granted by the AIMST University Human Ethics Committee (AUHEC) with the approval number Ref No: AUHEC/FOM/2022/01 for the implementation of the study. Informed consent forms were given and signed by all subjects prior to participation. Confidentiality of subjects were maintained.

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