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Stature Estimation of a Thai Population Using the Scapula

Estimación de la Estatura de una Población Tailandesa Utilizando la Escápula

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SUMMARY: Stature is an important component of biological profiles for forensic identification. In forensic situations, non-long bones might be needed for estimating stature if long bones are absent or fragmented. This study aimed to develop multiple regression model equations for stature estimation using scapula lengths in a Thai population. The sample included 200 dry scapula (100 male and 100 female) from the Osteology Research and Training Center, Faculty of Medicine, Chiang Mai University, Chiang Mai. Seven measurements were taken from the scapula for stature estimation. The results revealed that the maximum breadth of the scapula (MBS) provided the most accurate stature prediction model for the correlation coefficient and standard error of estimation (SEE) for males (r = 0.65, SEE = 5.96 cm), females (r = 0.60, SEE = 5.32 cm), and combined sexes (r = 0.79, SEE = 5.82 cm). The best multiple regression models were as follows: male stature (cm) = 75.57 + 6.42 MBS + 0.30 × the length of the glenoid fossa – superior angle (LGS), with a SEE of 5.67, female stature (cm) = 71.65 + 0.24 × the maximum height of the scapula (MHS) + 8.16 MBS – 1.02 × the maximum breadth of the glenoid fossa (MBG), with a SEE of 4.96 cm, combined sex stature (cm) = 52.61 + 0.25 MHS + 5.34 MBS + 0.25 LGS, with a SEE of 5.25 cm. This result indicates that the scapula is important in estimating the stature of skeletal remains in forensic cases, especially in a Thai population when long bones are unavailable for stature estimation.

KEY WORDS: Stature estimation; Scapula; Forensic anthropology; Thai population.

INTRODUCTION

Biological identification from skeletal remains is an essential process posing major problems in forensic science. Individual biological profiles, including ancestry, age, sex, and stature, provide valuable data, helping to reduce the number of potential missing persons (Austin & King, 2016). Stature is important in building biological profiles, particularly in forensic cases, providing a valuable clue during personal identification as to whether the unknown deceased or missing person is tall or short within their population (Christensen *et al*., 2014).

Two methods are widely used to estimate stature from skeletal remains: anatomical and mathematical (Lundy, 1985). The anatomical (full skeleton) method, which can be applied when all skeletal elements contributing directly to stature are available, is considered the most accurate estimation method. However, while the anatomical method estimates the total stature, it requires an almost complete skeleton, often unavailable in a forensic situation. The mathematical method, the most widely used for stature estimation, develops regression equations based on the correlation between stature and the individual skeletal parts (Pininski & Brits, 2014). Accordingly, mathematical methods enable the stature estimation of human skeletal remains.
Conversely, stature estimation using the mathematical method depends on specifying the population, genetics, nutrition, and environment (Dayal *et al*., 2008; Perkins *et al*., 2016). Consequently, the specific stature estimation of each population is required, with the most accurate estimates obtained when the sample investigated resembles that used to derive the regression equations. The regression equation from the long bones is recommended for estimating the stature of skeletal remains and provides the most accurate mathematical method. A previous study by Mahakkanukrauh *et al*. (2011) estimated stature from long bone lengths in a Thai population. The most accurate equation for estimating stature with the fibula produced the lowest standard error of estimation (SEE) of 4.89 cm in males, while the femur

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provided the lowest SEE of 5.21 cm in females. The correlation coefficients of bone length and height ranged from 0.66 to 0.77 among the stature estimation models, and the correlation coefficients of bone length and height ranged from 0.552 to 0.762.

However, in forensic investigations, the long bones are often only available in fragments or disappear and cannot be used to estimate height. Consequently, one must employ other human skeletal regions to estimate stature, such as sternum (Jeamamornrat *et al*., 2022), lumbar vertebrae (Suwanlikhid *et al*., 2020), and sacrum (Keereewan *et al*., 2023). The reported regression equations for stature estimation are based on the correlation between stature and skeletal parts in a Thai population. The results indicate that these other bones can be used to estimate stature.

Additionally, in forensic investigation, flat bones appear better preserved than long bones, which are often fragmented, scattered, or mixed (Giurazza *et al*., 2013). The scapula is a flat triangular bone in the upper thoracic region on the dorsal surface of the rib cage. It is a site of attachment for many muscles, usually well-preserved at the scene (Papaioannou *et al*., 2012), and previously investigated for estimating stature in many populations. Few reports describe stature estimation using the scapula in the Thai population. However, the scapula is often found during forensic investigations and is widely used to determine stature and sex (Zhang *et al*., 2016). Several studies have reported that the scapula can be used to estimate human stature based on 3D CT images, scan evaluation, and imaging techniques. For example, Raj *et al*. (2023) reported the relationship between stature and scapula height measured on a 3D volume-rendered technique (VRT); the accuracy in predicting stature was 3.99–4.94 cm for males and 4.49–5.27 cm for females. Elijah *et al*. (2021) evaluated stature estimation from the scapula using osteometry and radiographic techniques in Nigerian samples. They concluded that regression equations can be used successfully to estimate scapula length.

Few studies have reported stature estimation using the scapula in a Thai population. The scapula is often found in forensic situations and widely used in sex determination. Therefore, the present study aims to develop a stature estimation model from scapula measurements and test the accuracy of the resulting equations on a Thai population.

MATERIAL AND METHOD

This study was performed with the approval of the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, Thailand (No. 2564/08259) and the University of Phayao Human Ethics Committee, Phayao, Thailand (No. 1.1/023/64).

The total sample comprised 200 individuals: 75 males and 75 females for the training sample and 50 scapulae (25 males and 25 females) for the test sample, derived from the Osteology Research and Training Center, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand. The age at death ranged from 22 to 91, with a mean average age of 63.28. The age of males ranged from 22 to 91, with the mean age of the male sample being 64.13 with a standard deviation of 14.54 years. The age of females ranged from 27 to 90, with the mean age of the female sample being 64.09 with a standard deviation of 16.79 years.

The study used the left sides of the scapula bones. The sample population of Thais was obtained from a database containing death certificates indicating sex, year of birth, and age at death. Scapulae demonstrating fractures, trauma, anomalies, or bone pathology were excluded from this study. Seven variables of the scapula were measured to the nearest 0.01 mm using a digital sliding vernier caliper (Mitutoyo, São Paulo, Brazil) as shown in Figure 1. The techniques and abbreviations for all the variables in this study were adapted from Elijah *et al*. (2021), as follows:

1) Maximum height of the scapular (MHS): Direct maximum distance from the superior angle of the scapular to the inferior angle of the scapular.
2) Length of the axial margin (LAB): Direct maximum distance from the most inferior point of the glenoid fossa to the tip of the inferior angle.
3) Maximum breadth of the scapula (MBS): Distance from the midpoint on the dorsal margin of the glenoid fossa to midway between the two ridges of the scapula spine on the vertical margin.
4) Length of the scapular spine (LSS): Distance between the spinal axis at the vertebral margin to the most distal point of the acromion process.
5) Length of the glenoid fossa – superior angle (LGS): Distance from the midpoint on the glenoid fossa to the tip of the superior angle.
6) Maximum height of the glenoid fossa (MHG): Longest length across the glenoid fossa perpendicular to the anterior-posterior axis.
7) Maximum breadth of the glenoid fossa (MBG): Widest width across the glenoid cavity measured at a right angle to the axis of length of the glenoid fossa.

The data were analyzed using the Statistical Package for the Social Sciences, version 26 (SPSS 26). The statistical significance level was set at $p < 0.05$. Descriptive statistics were computed for the stature and scapula measurements, including minimum, maximum, and standard deviation, for all variables. The intraclass correlation coefficient (ICC) was employed to assess the agreement between and among observers using a sample of 30 randomly selected patellae (15 males and 15 females) for each measurement variable. The errors were collected and measured one week apart.

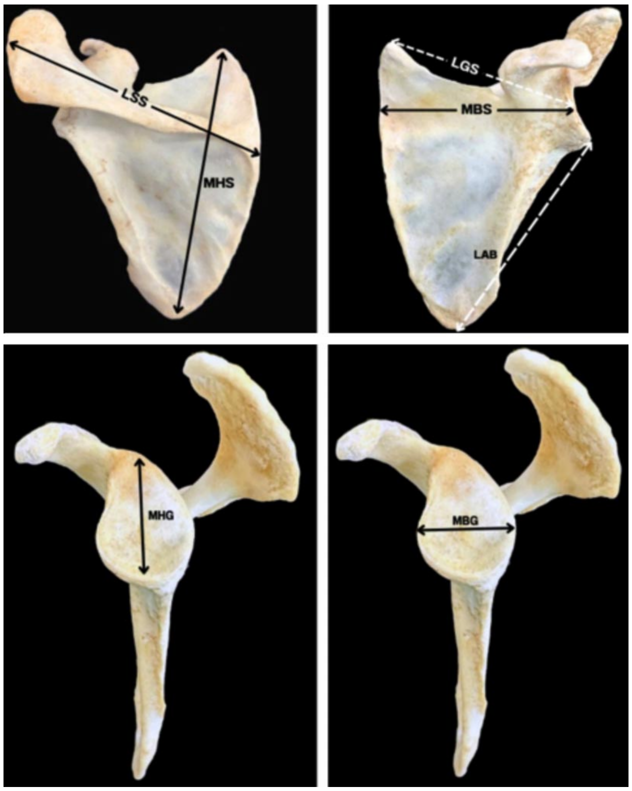

Fig. 1. Scapular measurements showing the length of scapular spine (LSS); maximum height of scapular (MHS); length of glenoid fossa – superior angle (LGS); length of axial margin (LAB); maximum breadth of the scapula (MBS); maximum height of glenoid fossa (MHG); maximum breadth of glenoid fossa (MBG).

The independent samples t-test was applied to compare the sexual dimorphism of each measurement, assuming the variables followed a normal distribution. If the variables did not meet this assumption, the Mann-Whitney test was employed instead. Additionally, linear regression models were developed to predict the stature of males, females, and both sexes using scapula measurements as the independent variable. Pearson correlation coefficients were used to evaluate the association between stature and the measured factors.

The mean, determined as the average absolute error, was used to determine the difference between predicted and corrected stature. This measure was used to analyze the efficacy of a regression model. Additionally, the percentage accuracy within the SEE was produced to evaluate the regression equations. A p-value below 0.05 was deemed statistically significant.

RESULTS

The ICC values of all measurements were in the range of 0.989–0.997 for intra-observer agreement and 0.860–0.998 for inter-observer agreement. These values represent almost excellent agreement.

The average stature measurements of the training group were 165.16 cm (n = 75) for males and 152.83 cm (n = 75) for females. Conversely, the test set group had average statures of 167.48 cm for males (n = 25) and 154.04 cm for females (n = 25).

Table I displays the results of the independent samples t-test and the Mann-Whitney test, indicating that all variables exhibited statistically significant differences between males and females, with $p < 0.05$, except for age (year). Furthermore, the average values of the variables for males were considerably greater than those for females across all variables. Statistically significant differences were observed in most scapula measurements between males and females.

Table II displays the results of a simple linear regression analysis. Linear regression models were created separately for males, females, and combined sexes using the obtained results. The maximum breadth of the scapula (MBS) showed the highest correlation coefficient (r = 0.79) and the lowest SEE of 5.82 cm when considering both sexes together. The MBS showed the highest correlation coefficient (r = 0.65) and the lowest SEE of 5.96 cm for males and a correlation coefficient of 0.60 and an SEE of 5.32 cm for females. The results of the simple linear regression analysis revealed that the MBS had the highest correlation with stature among all the variables.

Table III displays the multiple regression analysis used to predict stature. The findings of this study, including both males and females, showed that the maximum height of the scapula (MHS), MBS, and length of the glenoid fossa – superior angle (LGS) were the most suitable variables for predicting stature. These variables had the highest coefficient of determination (R2 = 0.70) and the lowest SEE of 5.25 cm. The multiple regression model for males was constructed using the MBS and LGS, which had a coefficient of determination of 0.48 and the lowest SEE of 5.67 cm. The multiple regression model for females was determined using the MHS, MBS, and maximum breadth of the glenoid fossa (MBG), yielding a coefficient of determination of R2 = 0.46 and the lowest SEE of 4.96 cm.

The findings revealed the mean absolute error resulting from multiple regressions on the test set group, which comprised 50 samples: 25 males and 25 females. The combined sexes had the lowest mean absolute error (5.43 cm) and the highest percentage accuracy within the first SEE of 66.09 %. In comparison, the mean absolute error range of the males and females was found to be lower than for the combined sexes at 6.01 cm and 5.95 cm, with the percentage accuracy within the first SEE being 37.80 and 27.16, respectively.

Table I. Descriptive statistics of scapula measurements.

Variable	Males (n=75)				Females (n=75)				P-value
	Min	Max	Mean	SD	Min	Max	Mean	SD	
Age (years)	22	91	64.13	14.54	27	90	64.09	16.79	0.988
Stature (cm)	150	183	165.16	7.75	140	170	152.83	6.60	< .001*
1.MHS	134.38	165.08	149.52	6.58	114.85	150.00	130.08	7.81	< .001*
2.LAB	114.60	144.64	130.87	6.49	101.31	132.87	117.38	7.44	< .001*
3.MBS	8.90	11.80	9.99	0.57	7.90	10.10	8.99	0.52	$_{MW}$ <.001
4.LSS	116.40	148.80	130.76	6.56	103.34	133.41	116.15	6.69	< .001*
5.LGS	67.12	102.08	84.40	7.83	64.04	95.29	77.45	6.25	< .001*
6.MHG	32.78	41.52	37.09	2.03	29.31	37.40	32.66	1.75	< .001*
7.MBG	23.93	31.32	27.13	1.73	19.49	27.23	22.84	1.61	< .001*

Min, minimum; Max, maximum; SD, Standard deviation * Statistically significant difference using the independent sample t-test or the Mann-Whitney U test (p < 0.05).

Table II. Simple linear regression for the estimation of scapula.

Sex	Variable (mm)	Sample size	Regression formulae	r	R^2	SEE	P-value
Overall	1.MHS	150	Y = 80.12 + 0.56 MHS	0.72	0.52	6.58	< .001
	2.LAB	150	Y = 63.38 + 0.73 LAB	0.75	0.56	6.31	< .001
	3.MBS	150	Y = 62.93 + 10.12 MBS	0.79	0.62	5.82	< .001
	4.LSS	150	Y = 69.40 + 0.73 LSS	0.76	0.57	6.23	< .001
	5.LGS	150	Y = 95.52 + 0.78 LGS	0.65	0.42	7.21	< .001
	6.MHG	150	Y = 86.93 + 2.07 MHG	0.64	0.41	7.33	< .001
	7.MBG	150	Y = 104.15 + 2.19 MBG	0.63	0.40	7.37	< .001
Male	1.MHS	75	Y = 82.49 + 0.55 MHS	0.47	0.22	6.89	< .001
	2.LAB	75	Y = 77.31 + 0.67 LAB	0.56	0.32	6.46	< .001
	3.MBS	75	Y = 77.12 + 8.81 MBS	0.65	0.42	5.96	< .001
	4.LSS	75	Y = 82.80 + 0.63 LSS	0.53	0.28	6.61	< .001
	5.LGS	75	Y = 117.04 + 0.57 LGS	0.58	0.33	6.38	< .001
	6.MHG	75	Y = 127.76 + 1.01 MHG	0.26	0.07	7.53	0.02
	7.MBG	75	Y = 128.81 + 1.34 MBG	0.30	0.09	7.45	0.01
Female	1.MHS	75	Y = 107.09 + 0.35 MHS	0.42	0.17	6.05	< .001
	2.LAB	75	Y = 97.92 + 0.47 LAB	0.53	0.28	5.65	< .001
	3.MBS	75	Y = 84.62 + 7.59 MBS	0.60	0.36	5.32	< .001
	4.LSS	75	Y = 91.09 + 0.53 LSS	0.54	0.29	5.60	< .001
	5.LGS	75	Y = 114.09 + 0.50 LGS	0.47	0.22	5.86	< .001
	6.MHG	75	Y = 114.45 + 1.17 MHG	0.31	0.10	6.32	0.01
	7.MBG	75	Y = 135.66 + 0.75 MBG	0.18	0.03	6.53	0.12

y, stature estimate in cm; x, value of each measurement in cm; r, correlation coefficient; R2, coefficient of determination; SEE, standard error of the estimate.

Table III. Multiple regression for the estimation of stature.

Sex	**Regression formulae**	**SEE (cm)**	**R^2**	**P-value**
Overall	Y = 52.61 + 0.25 MHS + 5.34 MBS + 0.25 LGS	5.25	0.70	< .001
Male	Y = 75.57 + 6.42 MBS + 0.30 LGS	5.67	0.48	< .001
Female	Y = 71.65 + 0.24 MHS + 8.16 MBS -1.02 MBG	4.96	0.46	< .001

DISCUSSION

Stature estimation is an important element of biological profile analyses geared toward identifying skeletal remains. When an investigation involves unknown, commingled skeletal remains, stature enables a forensic scientist to reduce the pool of possible victim matches (Krishan *et al*., 2012). Although long bones have proven useful for stature estimation, in many situations, these skeletal elements are not found. Therefore, a need remains for some means of estimating stature which does not use long bones. This study indicates that the scapula can be used to estimate the stature of an individual (Campobasso *et al*., 1998; Igwe & Akpuaka, 2013; Zhang *et al*., 2016; Raj *et al*., 2023).

Previous studies have developed discriminant functions using the scapula to estimate the sex of skeletal remains. Sex estimation is based on differences in both morphology and size since male and female scapulae differ in both the anterior and posterior aspects (Campobasso *et al*., 1998; Igwe & Akpuaka, 2013), while all measurements of male scapulae have been found to be larger than those of females; this finding is consistent with those of other studies (Igwe & Akpuaka, 2013; Zhang *et al*., 2016), including Peckmann *et al*. (2017). They studied sex estimation from the scapula in a Thai population comprising 191 samples (95 males and 96 females) and found that the length and breadth of the glenoid cavity demonstrated statistically significant differences between males and females. These results confirm that the glenoid cavity of the scapula in males is larger and higher than in females.

The present study revealed no statistically significant differences between the right and left scapulae in terms of mean length for all variables, while the mean values of male scapulae for each variable were greater than those of females. This finding is similar to previous studies (Campobasso *et al*., 1998; Igwe & Akpuaka, 2013; Zhang *et al*., 2016). The difference in mean length between males and females may be due to the greater development of upper limb muscles in males. Greater muscular development, leading to accompanying bone growth to ensure the support of the muscle tissue attached, is likely influenced by genetic factors that contribute to individual physical characteristics (Oliveira Costa *et al*., 2016).

The present study employs multiple regression formulae to provide forensic anthropologists and other forensic scientists with the means to estimate stature based on scapula measurements in a Thai population. Giurazza *et al*. (2013) reported a stature estimation model in an older Italian population using the scapula, which involved chest X-ray measurements. The results indicated that the mean error using a longitudinal scapula diameter (LSD) equation was 4.4 cm. Zhang *et al*. (2016) studied stature estimation using 3D images in a Chinese population, finding that they were able to predict stature with an accuracy of 5.252–7.210 cm for males and 4.630–6.484 cm for females. Zhang *et al*. (2019) studied 3D-VRT images in a Chinese population using multiple regression equations calculated to measure the clavicle, scapula, and sternum in relation to stature; the accuracy of stature prediction was 4.777–5.313 cm for males and 4.388–4.658 cm for females. Elijah *et al*. (2021) reported that the length of the axillary margin of the scapula is the best predictor of scapula length in a Nigerian population; they also found no statistically significant difference between the mean length derived from radiographs and actual bones. Torimitsu *et al*. (2015) established scapula measurements based on 3D images in a Japanese population and reported that longitudinal scapula lengths (LSL) had the lowest SEE, 4.22 cm in a combined sex sample of 3.75 cm for males and 4.37 cm for females. Compared with previous studies, the accuracy of the stature estimation model in this present study is better than that for a Nigerian population.

It is also important to note that the accuracy of stature estimated from the scapula may be influenced by the type of sample employed (e.g., dry bone, CT scans, 3D-VRT images, radiographs), as well as the height and age distribution of the samples. However, no previous studies have provided a detailed report on the age-related effects of stature estimation based on scapular height.

The accuracy of the stature estimation model differed between populations. This may be attributable to several factors affecting both the bone dimensions and stature of each population, including nutrition, genetics, and demographics (Perkins *et al*., 2016). Thus, regression estimates of stature should be created for each population. The stepwise multiple regression models acquired for stature estimation from scapula measurements provided superior correlation relative to the simple linear regression models for both combined sexes and females; however, stepwise models did not improve the accuracy for males. The MHS, MBS, and LGS were selected for the stature estimation model involving combined sex samples, with the MBS and LGS also selected for the male stature estimation model. However, the MHS, MBS, and MBG were selected for the female stature estimation model (Table III). In addition, Campobasso *et al*. (1998) measured scapulae from 80 individuals (40 males and 40 females) using seven parameters (maximum length, maximum breadth, maximum acrocoracoid distance, acromion length, maximum coracoid length, and length and width of the glenoid cavity). In an Italian population, they found the MBS and the MBG to be the best predictors of scapula length in males, whereas, in females, the maximum length of the coracoid process and the MBG were the best predictors. However, this study found that the MBS showed the highest correlation coefficient and was the best predictor in the Thai population.

The multiple regression testing presented lower mean absolute error and higher percentage accuracy in the first SEE of the combined sexes (66.09 %), resulting in a range of 4.48–6.59 cm. This suggests that it is advisable to include males and females simultaneously when constructing a regression model to predict stature in the Thai population.
One limitation of this study is the range of cadaver stature in males and females in the samples (150–165 cm and 140–172 cm, respectively). Stature estimation with different populations or height ranges should be used cautiously. Thus, it is suggested that future studies involve different populations, especially in cases where the suspected stature exceeds the stature range in this present study.

CONCLUSION

This study indicates that scapula measurements can be used for forensic stature estimation from skeletal remains in the Thai population, particularly where preferred predictors, such as long bones, are unavailable.

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CHOMPOOPHUEN, H.; PREEDALIKIT, K.; NAVIC, P. & MAHAKKANUKRAUH, P. Estimación de la estatura de una población tailandesa utilizando la escápula. *Int. J. Morphol., 42(6)*:1646-1652, 2024

RESUMEN: La estatura es un componente importante de los perfiles biológicos para la identificación forense. En situaciones forenses, es posible que se necesiten huesos no largos para estimar la estatura si los huesos largos están ausentes o fragmentados. Este estudio tuvo como objetivo desarrollar ecuaciones de modelos de regresión múltiple para la estimación de la estatura utilizando longitudes de escápula en una población tailandesa. La muestra incluyó 200 escápulas secas (100 de hombres y 100 de mujeres) del Centro de Investigación y Capacitación en Osteología, Facultad de Medicina, Universidad de Chiang Mai, Chiang Mai. Se tomaron siete medidas de la escápula para la estimación de la estatura. Los resultados revelaron que la anchura máxima de la escápula (MBS) proporcionó el modelo de predicción de estatura más preciso para el coeficiente de correlación y el error estándar de estimación (SEE) para hombres (r = 0,65, SEE = 5,96 cm), mujeres (r = 0,60, SEE = 5,32 cm) y sexos combinados (r = 0,79, SEE = 5,82 cm). Los mejores modelos de regresión múltiple fueron los siguientes: Estatura en hombres (cm) = 75,57 + 6,42 MBS + 0,30 × longitud de la fosa glenoidea – ángulo superior (LGS), con un SEE de 5,67, estatura en mujeres (cm) = 71,65 + 0,24 × altura máxima de la escápula (MHS) + 8,16 MBS – 1,02 × ancho máximo de la fosa glenoidea (MBG), con un SEE de 4,96 cm, estatura combinada de ambos sexos (cm) = 52,61 + 0,25 MHS + 5,34 MBS + 0,25 LGS, con un SEE de 5,25 cm. Este resultado indica que la escápula es importante para estimar la estatura de los restos óseos en casos forenses, especialmente en una población tailandesa en la que no se dispone de huesos largos para la estimación de la estatura.

PALABRAS CLAVE: Estimación de la estatura; Escápula; Antropología forense; Población tailandesa.

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