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Original Article

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Stature Estimation from the Sacrum in a Thai Population

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ABSTRACT

OBJECTIVE This study aimed to create equations for stature estimation using sacral lengths and to test the accuracy of the resulting equations in a Thai population.

METHODS The sample included 200 Thai skeletons (100 males and 100 females) from the Forensic Osteology Research Center, Faculty of Medicine, Chiang Mai University, Chiang Mai. Seven sacral measurements were made and stature estimation equations were created using simple linear regression analysis.

RESULTS The measurements for stature estimation with the highest correlation coefficient (r) and the lowest standard error of the estimate (SEE) were the combination of anterior sacral body heights of S1 + S2 ($y = 123.011 + (7.638x)$, $r = 0.564$, SEE = 4.527 cm) for males, the anterior sacral height ($y = 129.074 + (2.576x)$, $r = 0.460$, SEE = 5.112 cm) for females, and the vertebral body maximum width of S1 ($y = 105.197 + (12.829x)$, $r = 0.550$, SEE = 6.762 cm) for males and females combined, where y is the stature estimate in cm, and x is the value of the measurement in cm. The most accurate equations for stature estimation used the vertebral body height of S1 in both males and females which had the lowest value of mean absolute error and the standard error of prediction.

CONCLUSIONS The regression equations for stature estimation using sacral length in this study provided accurate stature estimates for both sexes, which suggests these equations can be used to estimation stature in human identification, especially in the Thai population.

KEYWORDS stature estimation, sacrum, Thai population

INTRODUCTION

Human identification is one of the most challenging aspects of forensic science. The four main pillars of biological identification that forensic examiners attempt to determine are sex, age, race, and stature. Stature estimation is an important process in forensic human identification. The benefit of stature estimation is that it narrows the exploration possibilities in the identification of deceased individuals, especially in the case of human skeletal remains (1). Stature has a proportional correlation with several parts of the human body, e.g., the cephalic region, trunk, and limbs. Current procedures for stature estimation include both anatomical and mathematical methods. The anatomical method (Fully's method) is considered the most accurate stature estimation technique and consists of the summation of measurements of upper and lower body segments of the human skeleton that contribute to stature, e.g., the skull, vertebral column, femur, tibia, and foot bones (2). However, the most widely used method for stature estimation is a mathematical method. This method of stature estimation depends on the use of sex-specific and population-specific regression equations (3). The regression equation for stature estimation is based on the correlation between stature and skeletal parts (4). The most accurate stature estimations are generated using long bone regression equations because human long bones are strongly associated with stature (5,6). Additionally, measurements of other human skeletal parts such as the skull (7), scapula (8), clavicle (9), and vertebrae (10), have also been used to estimate stature with good correlation.

Few studies, however, have performed stature estimation using the sacrum, especially in Thailand. The sacrum is often found at a forensic scene and is widely used to evaluate sex and age (11). Several studies have reported that sacral length can be used to estimate human stature with moderate accuracy (12-16). Pelin et al. (12) described stature estimation based on magnetic resonance imaging of the sacrum and coccyx (standard error of the estimate (SEE) = 6.59 cm). Giroux and Wescott (13) assessed the relationship between stature and sacral height measured on dry bones in American males and females (SEE = 6.96-7.73 cm). Pininski and Brits (14) evaluated stature estimation using sacral lengths in South African samples. They concluded that regression equations derived from the sacral lengths can be used for stature estimation with accurate results (SEE = 5.90-8.71 cm). Zhan et al. (15) studied stature estimation from sacral measurements using multidetector computed tomography in Chinese samples. They concluded that regression equations may be useful for accurate stature estimation (SEE = 5.55-5.83 cm). Lai et al. (16) assessed the relationship between pelvic and sacral lengths and stature using computed tomography images in Malaysian samples. They concluded that a combination of pelvic and sacral measurements contributed to a higher correlation coefficient. Currently, little is known about stature estimation using the sacrum in a Thai population. This study aimed to create equations for stature estimation using sacral lengths and to test the accuracy of the resulting equations in a Thai population.

METHODS

This study was approved by the University of Phayao Human Ethics Committee, Phayao, Thailand (No. 1.1/028/63) and the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand (No. 7679/2020). The sample consisted of 200 sacral bones (100 males and 100 females) of known age and sex obtained from the Forensic Osteology Research Center (FORC), Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand. The mean ages for males and females were 63.75 and 63.39 years, respectively. The samples were divided into two sets. The training set (75 males and 75 females) was used to create the equations for stature estimation, and the test set (25 males and 25 females) was used to test the accuracy of the resulting equations (Table 1). Specimens with obvious pathologies or

Table 1. Distribution of samples by age and sex

Age arange (year)	Training set (n=150)		Test set (n=50)	
	Male (n=75)	Female (n=75)	Male (n=25)	Female (n=25)
10-19	0	0	0	1
20-29	1	1	0	1
30-39	5	2	0	2
40-49	10	9	3	1
50-59	18	14	5	7
60-69	11	24	4	5
70-79	18	12	5	3
80-89	11	11	8	5
90-99	1	2	0	0

Table 2. Description of the sacral measurements

Measurement	Description
1. Anterior sacral height (ASH)	The distance from the promontory to the tip of the sacrum measured along the midline
2. Anterior sacral width (ASW)	The maximum transverse breadth of the sacrum measured at the anterior aspect of the auricular surface
3. Vertebral body maximum width of S1 (BWS1)	The widest transverse distance of S1 vertebral body
4. Vertebral body mid-diameter of S1 (BMS1)	The distance from anterior to posterior limits of the S1 vertebral body at the midline
5. Vertebral body height of S1 (BHS1)	The distance between superior and inferior limits of the S1 vertebral body at the midline
6. Vertebral body height of S2 (BHS2)	The distance between superior and inferior limits of the S2 vertebral body at the midline
7. Combination of anterior sacral body heights of S1+S2 (S1S2)	The total distance of anterior sacral body heights of S1 and S2

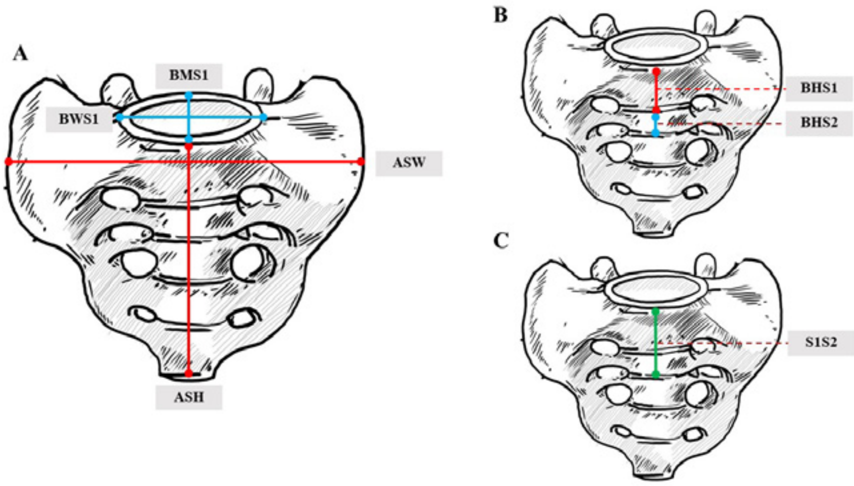

Figure 1. (A) Measurements of the anterior sacral height (ASH), anterior sacral width (ASW), vertebral body maximum width of S1 (BWS1), and vertebral body mid-diameter of S1 (BMS1); (B) Measurements of the vertebral body height of S1 (BHS1) and vertebral body height of S2 (BHS2); (C) Measurement of the combination of anterior sacral body heights S1 + S2 (S1S2).

fractures were excluded. The descriptions and images of sacral measurements are shown in Table 2 and Figure 1. All measurements were made using a digital sliding caliper (Mitutoyo, São Paulo, Brazil). The stature estimation equations were created separately for males, females, and combined sex. The values of each measurement and stature of the samples were used to develop the equations using simple linear regression.

Descriptive statistics for the stature and the sacral measurements were calculated including maximum, minimum, mean, and standard deviation. The intraclass correlation coefficient (ICC) was used to evaluate intra-observer and inter-observer agreement using 30 cases of each measurement. The correlation between stature and sacral measurement was evaluated by Pearson's correlation coefficient analysis. The independent sample t-test and Mann-Whitney U test were used to compare the mean values of sacral measurements between males and females when normality was available and unavailable, respectively. The level of statistical significance was set at 0.05 in the hypothesis testing. The statistical analysis was evaluated using the SPSS software package (IBM SPSS for Windows, Version 22, Chicago, IL, USA).

RESULTS

The ICC values of all measurements were in the range of 0.986 to 0.997 for intra-observer agreement and 0.846 to 0.996 for inter-observer agreement. These values represent almost perfect agreement. The mean stature values of the samples were 166.23 cm in males and 154.59 cm in females. The descriptive statistics of the sacral measurements for males (n = 75) and females (n = 75) are shown in Table 3. Statistically significant differences were observed between the males and females in most sacral measurements. Based on that result, stature estimation equations were created separately for males, females, and combined sex.

Tables 4-6 show the simple regression equations for stature estimation. For males, the combination of anterior sacral body height of S1 + S2 (Figure 1) had the highest correlation coefficient (r = 0.564) and the lowest SEE (4.527 cm). For females, the anterior sacral height had the greatest correlation coefficient (r = 0.460) and the smallest SEE (5.112 cm). For combined sex, the vertebral body maximum width of S1 (BWS1) had the greatest correlation coefficient (r = 0.550) and the lowest SEE (6.762 cm).

Table 7 shows the mean absolute error (MAE) and the standard error of prediction (SEP) after the application of stature estimation equations to the test samples (n = 50). In both males and females, the vertebral body height of S1 had the lowest MAE and SEP (MAE = 4.69 cm and SEP = 5.32 cm for males, and MAE = 4.31 cm and SEP = 5.34 cm for females). For combined sex, the vertebral body mid-diameter of S1 had the lowest MAE (5.64 cm) and SEP (6.81 cm).

DISCUSSION

Since an intact skeleton is rarely found in the forensic field, mathematical methods are widely used for stature estimation analysis. Most mathematical methods are based on long bone lengths. However, human long bones are not recovered in many situations. Therefore, it is important to be able to use other bones to estimate stature. Stature estimations using the sacrum from several populations have reported population-specific regression equations (12-16). However, anthropometric proportions vary among populations, variations which are attributed to genetic and environmental factors (17). For that reason, it is important to create population-specific regression equations for each population.

According to our results, the mean differences of stature in Thai populations between our study (166.23 cm in males and 154.59 cm in females) and a study by Sangvichien et al. (18) (164.10

Table 3. Sacral measurements and mean values (cm) of males (n=75) and females (n=75)

Measurement	Males				Females				*p*-value
	Min	Max	Mean	SD	Min	Max	Mean	SD	
1. ASH	7.89	12.17	10.13	0.92	7.37	12.87	9.90	1.02	0.139
2. ASW	8.62	11.01	9.60	0.49	8.05	11.33	9.86	0.64	0.006*
3. BWS1	3.60	5.15	4.47	0.30	3.57	4.88	4.13	0.30	0.000*
4. BMS1	2.71	4.00	3.23	0.22	2.55	3.63	2.92	0.19	0.000*
5. BHS1	2.59	3.79	3.09	0.24	2.46	3.63	2.99	0.23	0.012*
6. BHS2	1.84	3.33	2.56	0.29	1.78	3.10	2.50	0.28	0.277 MW
7. S1S2	4.69	6.74	5.65	0.40	4.55	6.53	5.50	0.40	0.020*

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

Table 4. Regression equations to estimate stature in males (n=75)

Measurement	Equation	r	r^2	SEE
1. ASH	y = 144.644 + (2.129x)	0.362	0.131	5.112
2. ASW	y = 122.162 + (4.588x)	0.420	0.177	4.976
3. BWS1	y = 143.259 + (5.137x)	0.283	0.080	5.259
4. BMS1	y = 147.581 + (5.708x)	0.331	0.110	5.174
5. BHS1	y = 131.732 + (11.153x)	0.493	0.243	4.772
6. BHS2	y = 148.988 + (6.720x)	0.366	0.134	5.102
7. S1S2	y = 123.011 + (7.638x)	0.564	0.319	4.527

y, stature estimate in cm; x, value of each measurement in cm; r, correlation coefficient; r^2, coefficient of determination; SEE, standard error of the estimate

Table 5. Regression equations to estimate stature in females (n=75)

Measurement	Equation	r	r^2	SEE
1. ASH	y = 129.074 + (2.576x)	0.460	0.212	5.112
2. ASW	y = 130.672 + (2.424x)	0.274	0.075	5.537
3. BWS1	y = 126.142 + (6.878x)	0.367	0.135	5.356
4. BMS1	y = 146.380 + (2.802x)	0.095	0.009	5.732
5. BHS1	y = 127.998 + (8.880x)	0.361	0.130	5.370
6. BHS2	y = 138.559 + (6.391x)	0.318	0.101	5.458
7. S1S2	y = 121.294 + (6.050x)	0.428	0.184	5.203

y, stature estimate in cm; x, value of each measurement in cm; r, correlation coefficient; r^2, coefficient of determination; SEE, standard error of the estimate

Table 6. Regression equations to estimate stature in combined sex (n=150)

Measurement	Equation	r	r^2	SEE
1. ASH	y = 129.717 + (3.063x)	0.372	0.138	7.514
2. ASW	y = 151.826 + (0.881x)	0.064	0.004	8.077
3. BWS1	y = 105.197 + (12.829x)	0.550	0.302	6.762
4. BMS1	y = 118.024 + (13.683x)	0.528	0.279	6.875
5. BHS1	y = 115.942 + (14.609x)	0.436	0.190	7.284
6. BHS2	y = 138.884 + (8.485x)	0.307	0.094	7.704
7. S1S2	y = 108.521 + (9.298x)	0.472	0.225	7.134

y, stature estimate in cm; x, value of each measurement in cm; r, correlation coefficient; r^2, coefficient of determination; SEE, standard error of the estimate

Table 7. Mean absolute error (MEA) and standard error of prediction (SEP) after application of stature estimation equations to the test sample

Measurement	MAE (cm)			SEP (cm)		
	Male	Female	Combined sex	Male	Female	Combined sex
1. ASH	4.97	4.84	6.07	5.50	5.71	7.54
2. ASW	4.80	4.99	6.58	5.34	5.76	8.06
3. BWS1	4.74	4.80	6.11	5.59	5.86	7.22
4. BMS1	4.71	4.63	5.64	5.62	5.61	6.81
5. BHS1	4.69	4.31	5.78	5.32	5.34	7.04
6. BHS2	5.40	4.68	6.58	5.95	5.80	8.14
7. S1S2	5.46	4.53	6.14	5.93	5.70	7.72

cm in males and 151.70 cm in females) may be an indication of a secular change in stature in Thailand. Thai males in our study were taller than the Thai males in the Sangvichien et al. study by 2.1 cm and the females were taller by 2.9 cm. This change is a reflection of an estimated difference in birth year of about 35 years between the samples.

Additionally, our results showed that all sacral measurements were longer in males compared to females, with the exception of the anterior sacral width which was longer in females. The study by Krogman and Iscan reported that the female sacrum tends to be shorter and broader, while the male sacrum is longer and narrower (19). These differences are associated with adaptations of the female pelvis for parturition and locomotion (19). Similarly, Mishra et al. (20) stated that the male sacrum was significantly longer than the female sacrum. These results suggest sexual dimorphism of the sacral and coccyx lengths. In addition, Lazarevski (21) stated that the aging process induces backward and downward displacement of the sacrum together with changes that enlarge the pelvic bone system caudally. For that reason, in our study the relationship between stature and sacral length was evaluated separately for males and females.

Table 8. Mean absolute error (MEA) and standard error of prediction (SEP) after application of stature estimation equations to the test sample

Authors	Methods	Population	Sex	Sample size	r	SEE (cm)
Present study	Dry bone	Thai	Male	75	0.362	5.112
			Female	75	0.460	5.112
			Combined sex	150	0.372	7.514
Lai et al., 2021 (16)	CT	Malaysian	Combined sex	305	0.369	8.739
Zhan et al., 2018 (15)	CT	Chinese	Male	190	0.416	5.83
			Female	160	0.294	5.55
Pininski and Brits, 2014 (14)	Dry bone	Black African	Male	50	0.370	6.69
			Female	58	0.530	5.90
			Combined sex	108	0.550	7.30
			Male	51	0.250	8.53
			Female	51	0.330	6.59
		White African	Combined sex	102	0.320	8.71
Giroux and Wescott, 2008 (13)	Dry bone		Male	57	0.460	6.96
		Black American	Female	38	0.440	7.21
			Male	92	0.390	7.17
		White American	Female	60	0.130	7.73
Pelin et al., 2005 (12)	MRI	Caucasian	Male	42	0.432	6.59

Comparison of the accuracy of stature estimation using simple linear regression and multiple regression found no differences between the two methods. Therefore, we selected only simple linear regression for this study.

For males, the combination of anterior sacral body height of S1 + S2 was the measurement for stature estimation which had the highest correlation (r = 0.564) and the lowest SEE (4.527 cm). For females, the anterior sacral height was the measurement for stature estimation with the highest correlation (r = 0.460) and the lowest SEE (5.112 cm). For combined sex, the vertebral body maximum width of S1 was the measurement for stature estimation with the highest correlation (r = 0.550) and the lowest SEE (6.762 cm). In contrast, Pininski and Brits (14) found that the vertebral body height of S1 was the best stature predictor for males (r = 0.48, SEE = 6.31 cm), and the combination of anterior sacral body heights of S1 + S2 to have the best stature predictor for females (r = 0.56, SEE = 5.74 cm) in South African populations.

Using measurement of anterior sacral height, it was previously reported that stature was correlated with sacral height (Table 8). For example, Giroux and Wescott (13) obtained the anterior sacral heights of American Black and White populations of both sexes. They found that the SEE values were 6.96 cm in males and 7.21 cm in females in American Blacks, but were 7.17 cm in males and 7.73 cm in females in American Whites. Both of these SEE values are greater than in our study (SEE = 5.112 cm) of Thai males and females. These differences may be related to the variations observed in body proportion between the populations (2).

Finally, the stature estimation equations obtained in this study can be applied using sacral lengths in a Thai population. We recommend the following equations:

$$\text{Male stature (cm)} = 131.732 + (11.153 \times \text{BHS1}) \quad (1)$$

$$\text{Female stature (cm)} = 127.998 + (8.880 \times \text{BHS1}) \quad (2)$$

$$\text{Combined sex stature (cm)} = 118.024 + (13.683 \times \text{BMS1}) \quad (3)$$

where BHS1 = vertebral body height of S1 and BMS1 = vertebral body mid-diameter of S1.

CONCLUSIONS

The regression equations using sacral lengths in this study provide accurate stature estimate for both sexes in Thai population. These equations can be used to estimate stature, especially in cases when better estimators, such as the long bones, are not available. It is recommended that future research explore other features of the sacrum, e.g., the distance to the top of the pelvic girdle, for stature estimation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Cordeiro C, Muñoz-Barús JI, Wasterlain S, Cunha E, Vieira DN. Predicting adult stature from metatarsal length in a Portuguese population. Forensic Sci Int. 2009;193:131.e1-131.e1314.
2. Raxter MH, Auerbach BM, Ruff CB. Revision of the Fully technique for estimating statures. Am J Phys Anthropol. 2006;130:374-84.
3. Dayal MR, Steyn M, Kuykendall KL. Stature estimation from bones of South African whites. S Afr J Sci. 2008;104:124-8.
4. Sjøvold T. Stature estimation from the skeleton, In: Siegel J, Saukko P, Knupfer G, editors. Encyclopedia Forensic Sciences. London: Academic Press, 2000; p. 276- 84.
5. Bidmos MA. Stature reconstruction using fragmentary femora in South Africans of European descent. J Forensic Sci. 2008;53:1044-8.
6. Hauser R, Smoliński J, Gos T. The estimation of stature on the basis of measurements of the femur. Forensic Sci Int. 2005;147:185-90.
7. Ryan I, Bidmos MA. Skeletal height reconstruction from measurements of the skull in indigenous South Africans. Forensic Sci Int. 2007;167:16-21.
8. Campobasso CP, Di Vella G, Introna F Jr. Using scapular measurements in regression formulae for the estimation of stature. Boll Soc Ital Biol Sper. 1998;74:75-82.
9. Rani Y, Naik SK, Singh AK, Murari A. Correlation of stature of adult with the length of the clavicle. J Ind Acad Forensic Med. 2011;33:194-6.
10. Nagesh KR, Pradeep Kumar G. Estimation of stature from vertebral column length in South Indians. Leg Med (Tokyo). 2006;8:269-72.
11. Passalacqua NV. Forensic age-at-death estimation from the human sacrum. J Forensic Sci. 2009; 54:255-62.
12. Pelin C, Duyar I, Kayahan EM, Zağyapan R, Ağildere AM, Erar A. Body height estimation based on dimensions of sacral and coccygeal vertebrae. J Forensic Sci. 2005;50:294-7.
13. Giroux CL, Wescott DJ. Stature estimation based on dimensions of the bony pelvis and proximal femur. J Forensic Sci. 2008;53:65-8.
14. Pininski M, Brits D. Estimating stature in South African populations using various measures of the sacrum. Forensic Sci Int. 2014;234:182.e1-182.e1827.
15. Zhan MJ, Fan F, Qiu LR, Peng Z, Zhang K, Deng ZH. Estimation of stature and sex from sacrum and coccyx measurements by multidetector computed tomography in Chinese. Leg Med (Tokyo). 2018;34:21-6.
16. Lai PS, Mohamad Noor MH, Abdullah N. Stature estimation study based on pelvic and sacral morphometric among Malaysian population. Bull Natl Res Cent. 2021;45:1-12.
17. Choi BY, Chae YM, Chung IH, Kang HS. Correlation between the postmortem stature and the dried limb-bone lengths of Korean adult males. Yonsei Med J. 1997;38:79-85.
18. Sangvichien SJ, Srisurin V, Watthanayingsakul V. Estimation of stature of Thai and Chinese from the length of femur, tibia and fibula. Siriraj Hosp Gaz 1985;37:215-8.
19. Krogman WM, Iscan MY, The Human Skeleton in Forensic Medicine, second ed. Charles C. Springfield, IL: Thomas Publisher, 1986.
20. Mishra SR, Singh PJ, Agrawal AK, Gupta RN. Identification of sex of sacrum of Agra region. J Anat Soc India. 2003;52:132-6.
21. Lazarevski MB. Pelvic bone system changes and pathogenesis of genital prolapse: a radiopelvimetric study. Gynaecol Perinatol. 2004;13:1-12.